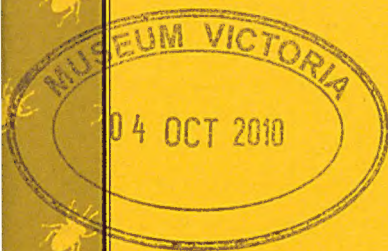


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Cover: This undescribed species of *Myrmecoroides* (Heteroptera: Miridae) is about 5 mm in length and occurs along the Great Dividing Range from southeast Queensland to Victoria. It is found on native grasses. The species is sexually dimorphic, with fully-winged males and short-winged females (illustrated here).

All species of *Myrmecoroides* are strongly ant-mimetic. This species is being described by Gerry Cassis of the University of New South Wales and Michael Wall of the San Diego Natural History Museum.

Illustration by Hannah Finlay.

A REVIEW OF *TAENARIS* HÜBNER (LEPIDOPTERA: NYMPHALIDAE: AMATHUSIINAE) IN QUEENSLAND, TOGETHER WITH FIRST AUSTRALIAN RECORDS FOR *T. MYOPS KIRSCHI* STAUDINGER AND *ELYMNIA AGONDAS MELANIPPE* GROSE-SMITH (SATYRINAE)

TREVOR A. LAMBKIN

Queensland Primary Industries and Fisheries, Department of Employment, Economic Development and Innovation, 665 Fairfield Road, Yeerongpilly, Qld 4105. (Trevor.Lambkin@deedi.qld.gov.au)

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Abstract

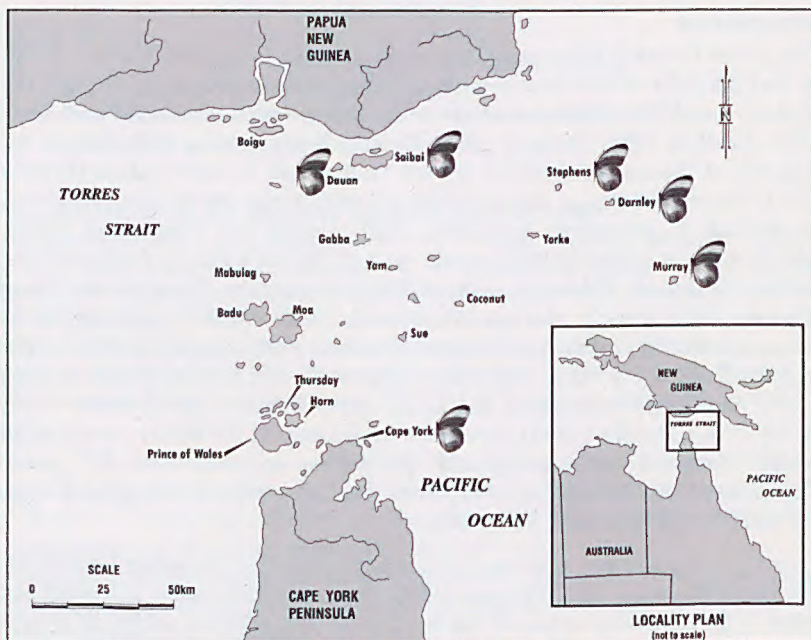
Species of the amathusiine genus *Taenaris* Hübner known to occur in Australia, predominantly from Torres Strait, are reviewed and illustrated. *T. myops kirschi* Staudinger is recorded for the first time in Australia from four male specimens collected on Dauan Island, Torres Strait. A female specimen of the satyrine *Elymnias agondas melanippe* Grose-Smith also collected from Dauan Island represents the first record of this taxon from Australia. The high degree of variation observed in the external facies of *Taenaris* from Torres Strait and reliable taxonomic separation of female specimens are discussed. *Taenaris*-like forms of the papilionid, *Papilio aegues ormenus* Guérin-Ménéville and *E. a. melanippe* from Torres Strait and Dauan Island respectively are illustrated and reviewed. The form of *P. a. ormenus* from Torres Strait that is most similar to *Taenaris* spp is identified as form *ormenus* Guérin-Ménéville variety *onesimus* Hewitson.

Introduction

The genus *Taenaris* Hübner, 1819 contains around 25 species (Parsons 1998) of owl butterfly which have a wide distribution from Malaysia, through the Moluccas and New Guinea, and out to the Solomons (Corbet and Pendlebury 1992, Parsons 1998, Tennent 2002). Despite this extensive distribution, the majority of species are confined to New Guinea and its outer islands (Brooks 1950, Parsons 1998), i.e. east of Weber's line (Brooks 1950). The exceptions to this are *T. horsfieldii* Swainson, 1820 (Corbet and Pendlebury 1992), which is the only species that occurs west of Weber's line in the Sundaland region (Malaysia, Palawan, western Borneo, southern Sumatra and Java) (Brooks 1950), and *T. phorcas* (Westwood, 1958) which is endemic to the Bismarck and Solomon Archipelagos (Parsons 1998, Tennent 2002). South of New Guinea, *Taenaris* occurs in Torres Strait and extends south to Cape York, Australia (Waterhouse and Lyell 1914, Johnson and Johnson 1991, Braby 2000). Brooks (1950) provided a useful map of the Malay Archipelago which illustrates the geographical distribution and limits of the genus. *Taenaris urania* (Linnaeus, 1758) from the Moluccas is the generic type species (Waterhouse and Lyell 1914).

Taenaris are attractive, medium to large butterflies (♂♂ forewing lengths 40-56 mm with larger ♀♀; Parsons 1998), predominantly white in colour but often with extensive areas of black, grey or tan (Brooks 1950, D'Abreu 1978, Parsons 1998). They characteristically have large round hindwings, with striking ocelli that are predominantly yellow in colour with central blue-black pupil areas. The ocelli are particularly obvious on the verso surface and

are considered to contribute to their aposematic colour patterns (Merrett 1996). The wings of *Taenaris* butterflies are relatively fragile and tear easily. Both sexes of many *Taenaris* species are highly polymorphic, so much so that their variability can tend to overlap between some species, making delimitation of these difficult, especially female specimens (Brooks 1950, Parsons 1991, 1998), although Brooks (1950) indicated that structural differences between the genital armatures of the males could be reliably used to identify males of *Taenaris* spp. Based on external facies, *Taenaris* males are characterised by having the inner margin of the forewing convex or bowed near the base, curving to the tornus, with tufts of long androconial hairs at the base of the upper side hindwing and an androconial hair-streak along the hindwing dorsal inner margin. Some species also have androconial scales underlying this inner marginal hair-streak (Brooks 1950, Parsons 1998, Braby 2000). Females typically have much broader wings with a straight forewing inner margin and lack androconial hairs and scales. Many species are believed to form Müllerian mimetic complexes; these complexes are also thought to incorporate, as probable Batesian mimics, pale forms of *Papilio aegeus* Donovan, 1805 (Papilionidae) and *Elymnias agondas* (Boisduval, 1832) (Nymphalidae) (Parsons 1984, Braby 2000).

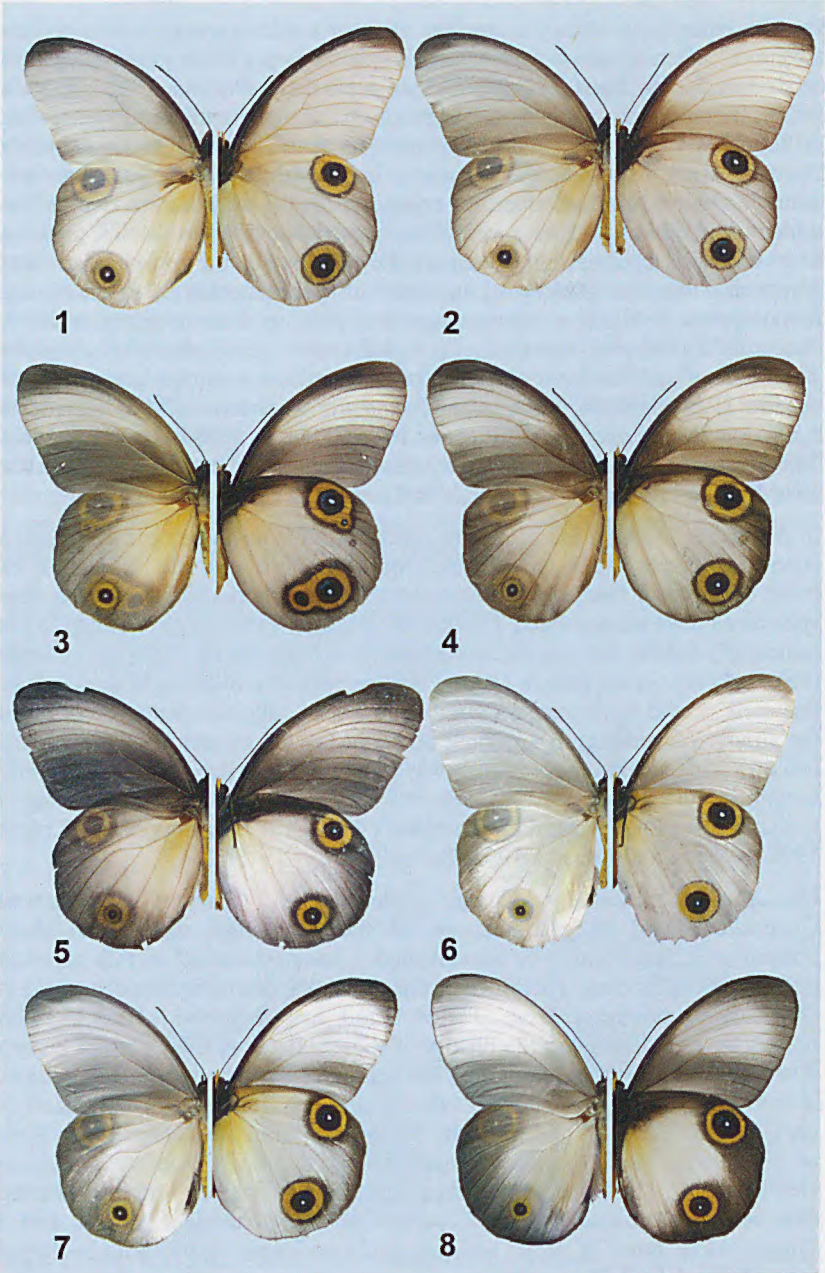


Map 1. Map of Torres Strait, Queensland showing positions of main or inhabited islands with known locations for *Taenaris* spp. indicated.

Despite being large showy butterflies, *Taenaris* are surprisingly secretive as they most often frequent the well shaded understorey of dense primary and secondary forest, from low to moderate elevations (Parsons 1998, Tennent 2002). In the understorey they often perch on the upper surface of vegetation, sometimes close to the ground (Parsons 1998, Tennent 2002) and quite often fly only when disturbed. Consequently, individuals are not often observed. Adult *Taenaris* primarily feed on rotting fruit and seeping sap within the understorey, although Parsons (1984) reported two species imbibing juices from damaged cycad fronds and nuts. Of the species for which larval host plants are recorded almost all of these utilise monocotyledons, with the gymnosperm family Cycadaceae also recorded as a host (Parsons 1998, Braby 2000). Despite *Taenaris* being a well known genus, the life histories of a number of species have only just been described over the last couple of decades (Parsons 1984, Johnson and Johnson 1991, Merrett 1996). Larvae of many species are gregarious (Parsons 1984). Parsons (1984) considered that *Taenaris* are normally continuously brooded, but reported pupal diapause occurring during times of prolonged dry periods.

In Australia, *Taenaris* are primarily confined to the northernmost and eastern islands of Torres Strait, Queensland (Map 1), and due to the remoteness of these islands and the secretive nature of the adult butterflies, relatively few specimens have been collected. Early historical specimens (prior to 1911) are principally held in the Australian Museum and Museum of Victoria, although there are a few in the British Natural History Museum (NHM), London. After this early period there were no further specimens collected from Torres Strait for almost 75 years until airstrips were constructed on many of the islands and efficient travel to these islands was possible. Since the 1980s, many more specimens of *Taenaris* have been collected in Torres Strait including a specimen from the Australian mainland (Wood 1987, Lambkin and Knight 1990, Johnson and Johnson 1991, Braby 2000).

Due to the temporally disjunct collections of *Taenaris* in northern Queensland, and since almost all of the knowledge relating to these butterflies is fragmentary or unpublished, I have attempted in this paper to pull together this data. Therefore in this work, the *Taenaris* spp occurring in Queensland, primarily from Torres Strait are reviewed. This includes presenting and discussing the history of their collection, their current known distributions, and some taxonomic difficulties within the group. In addition, information on their habits, prevalence and seasonality in Queensland is provided. I also report and illustrate for the first time the *Taenaris*-like form of *Papilio aegeus ormenus* Guérin-Méneville, 1831 variety *onesimus* Hewitson, 1858 that occurs in Torres Strait. Lastly, I report and illustrate the first records for Australia of *T. myops kirschi* Staudinger, 1887 and a *Taenaris*-like form of *E. a. melanippe* Grose-Smith, 1894, both collected from Dauan Island, Torres Strait.



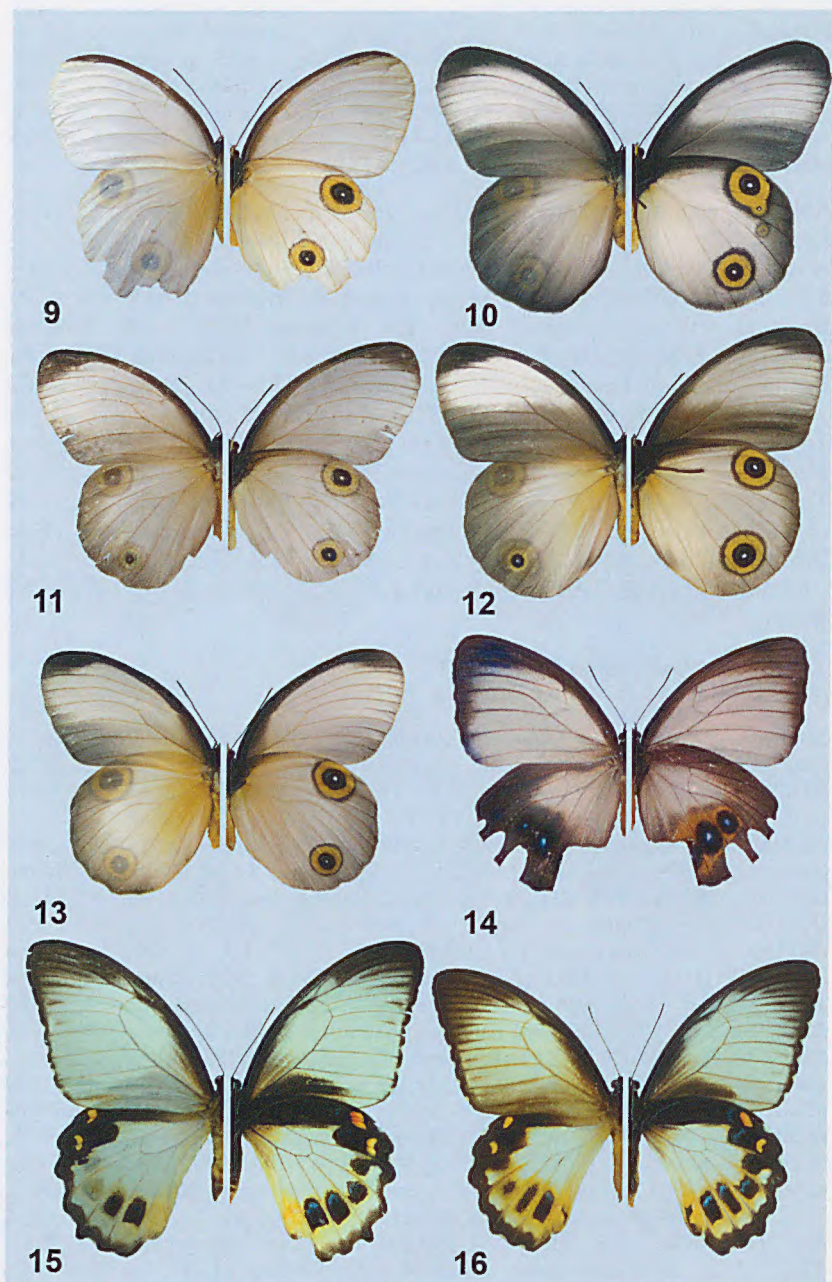
Figs 1-8 (Left). *Taenaris* spp males: Torres Strait, Queensland. All figures not to scale: upperside left, underside right [forewing lengths, in mm, in square brackets]. (1-5) *T. artemis jamesi*: (1) Dauan Island, 21.iv.2001 [46], AIK; (2) Murray Island, 25.iv.1989 [50], AIK; (3) Dauan, 28.ii.2006 [45], AIK; (4) Dauan, 25.iv.2000 [43], AIK; (5) Dauan, 9.iii.2006 [47], AIK; (6-8) *T. myops kirschi*: (6) Dauan, 6.iii.2006 [48], AIK; (7) Dauan, 10.iii.2006 [47], AIK; (8) Dauan, 24.ii.2006 [49], AIK.

Abbreviations of collectors, collections and their locations are: AIK – A.I. Knight; AJJ – A.J. Johnson; AM – Australian Museum, Sydney; ANIC – Australian National Insect Collection, Canberra; CEM – C.E. Meyer; CGM – C.G. Miller; CGMC – C.G. Miller collection, Lennox Head; EH – E. Hamacek; HE – H. Elgner; IRJ – I.R. Johnson; IRJC – I.R. Johnson collection, Brisbane; JWCD – J.W.C. d'Apice; KB – K. Beattie; KBC – K. Beattie collection, Brisbane; KH – K. Houston; MDB – M. De Baar; MDBC – M. De Baar collection, Brisbane; MTQ – Museum of Tropical Queensland, Townsville; MV – Museum of Victoria, Melbourne; NHM – Natural History Museum, London; PSV – P.S. Valentine; PSVC – P.S. Valentine collection, Townsville; QPFC – Queensland Primary Industries and Fisheries collection, Brisbane; SJJ – S.J. Johnson; SSB – S.S. Brown; SSBC – S.S. Brown collection, Bowral; TAL – T.A. Lambkin; TLF – T.L. Fenner; TLIKC – Joint collection of T.A. Lambkin and A.I. Knight, Brisbane; WWB – W.W. Brandt.

Taenaris artemis jamesi Butler, 1877

(Figs 1-5, 11-13)

Material examined or reviewed. MAINLAND QUEENSLAND: 1♂, North Queensland (NHM); 1♀, Lockerbie, Cape York, 8.vi.1990 SJJ (MTQ). TORRES STRAIT: 6♂♂, 1♀, Darnley Island, 13.iv.1910 (1♂), 18.iv.1910 (1♂), 21.iv.1910 (1♂), 22.iv.1910 (3♂♂), 18.v.1910 (1♀) HE (MV); 3♂♂, 2♀♀, same data except .xii.1909 (1♀), 22.iv.1910 (1♂, 1♀), 18.v.1910 (1♂), 19.v.1910 (1♂) (AM); 1♂, same data except 6-12.iv.1984 JWD (ANIC); 1♂, 1♀, Murray Island (NHM); 1♂, same data except 11-12.v.1995 SJJ (MTQ); 3♂♂, same data except 13-17.iv.1993 SJJ & IRJ (MTQ); 4♂♂, same data except 2.iv.1989 (3♂♂), 3.iv.1989 (1♂) IRJ & AJJ (MTQ); 1♂, same data except 3.iv.1989 IRJ & AJJ (IRJC); 1♂, 1♀, same data except 20.iv.1989 (1♀), 17.iv.1993 (1♂) SJJ & IRJ (PSVC); 3♂♂, same data except 17.iv.1993 (1♂), 17.iv.1994 (2♂♂) PSV (PSVC); 2♂♂, same data except 4.iv.1986 MDB (MDBC); 4♂♂, 1♀, same data except 30.iii.1986 (1♀), 22-25.iv.1989 (3♂♂), 26.iv.1996 (1♂) TAL (TLIKC); 1♂, same data except 4.iv.1986 KB (KBC); 7♂♂, same data except 24.iv.1989 (1♂), 25.iv.1989 (3♂♂), 22-25.iv.1989 (3♂♂) AIK (TLIKC); 2♂♂, same data except 6-10.iv.2001 SSB & CEM (SSBC); 1♂, same data except 1-7.vi.1986 JWD (ANIC); 3♂♂, Dauan Island, 2.iv.2004 PSV (PSVC); 3♂♂, same data except 2.iv.2004 (2♂♂), 3.iv.2004 (1♂) SJJ (MTQ); 2♂♂, same data except 1-8.iv.2009 MDB (MDBC); 3♂♂, same data except 5.iv.2009 CGM (CGMC); 7♂♂, 5♀♀, same data except 6.i.2006 (1♀), 11.i.2006 (2♀♀), 2.iv.2009 (1♂), 3.iv.2009 (1♂, 1♀), 5.iv.2009 (3♂♂), 6.iv.2009 (2♂♂), 6.i.2010 (1♀) TAL (TLIKC); 17♂♂, 7♀♀, same data except 25.iv.2000 (1♂), 7.v.2000 (1♀), 21.iv.2001 (1♂), 4.i.2006 (1♀), 23.ii.2006 (1♂), 24.ii.2006 (1♂), 28.ii.2006 (2♂♂), 6.iii.2006 (1♂,



Figs 9-16 (Left). *Taenaris* spp. females, and *Taenaris*-like forms of *Elymnias agondas melanippe* and *Papilio aegeus ormenus*: Torres Strait, Queensland. All figures not to scale: upperside left, underside right [forewing lengths, in mm, in square brackets]; (9) *T. catops turdula*: Saibai Island, 1.iii.1996 [50], TAL; (10-13) *T. artemis jamesi*: (10) Dauan Island, 11.iii.2006 [51], AIK; (11) Dauan, 11.i.2006 [51 mm], TAL; (12) Dauan, 6.iii.2006 [54], AIK; (13) Dauan, 9.iii.2006 [57], AIK; (14) *E. a. melanippe* female: Dauan, 4.iv.2009 [44], MDB; (15-16) *P. a. ormenus* females: (15) Dauan, 6.i.2006 [65], TAL; (16) Murray Island, 1.v.1999 [60], AIK.

1♀, 8.iii.2006 (1♂, 9.iii.2006 (6♂♂, 1♀), 10.iii.2006 (2♂♂, 10.ii.2008 (1♀), 11.iii.2006 (1♂, 1♀), 19.xii.2009 (1♀) AIK (TLIKC); 1♀, same data except 13-19.iv.2001 SSB (SSBC); ♂, ♀, Saibai Island, 20.iv.2000 AIK (TLIKC); 4♂♂, Stephens Island, 7.v.1985 (3♂♂), 11.v.1985 (1♂) CGM (CGMC). PAPUA NEW GUINEA: 1♀, Lae, 20.ix.1951, WWB, determined TLF 1975 (ANIC); 1♀, Subitana (Central District) 1800 ft, 11.viii.1949 WWB, ID by WWB (ANIC); 1♀, same data except 16.viii.1949.

Taenaris artemis (S.C. Snellen van Vollenhoven, 1860) occurs on the western side of New Guinea from Gebe, Waigeo, Misool, Aru, Salawati, Mioswaar, Biak and Japen, throughout New Guinea, including the outlying islands of Papua New Guinea and south through Torres Strait to the tip of Cape York Peninsula, Queensland (Brooks 1950, Parsons 1998, Braby 2000). The type locality is New Guinea (Waterhouse and Lyell 1914, Edwards *et al.* 2001). In Papua New Guinea it is widespread and occurs in a variety of habitats, including primary and secondary forest, and eucalypt savannah (Parsons 1998). Populations from southern Papua New Guinea and Torres Strait are assigned to *T. a. jamesi* (Brooks 1950, Parsons 1998). The type locality for *T. a. jamesi* (originally described as *Tenaris jamesi* Butler) is Yule Island, New Guinea (Butler 1876, Parsons 1998). Prior to Wood (1987) collecting three specimens of *T. a. jamesi* on Murray Island in Torres Strait in 1984/85 (Map 1), all previous known specimens from Australia predated 1911. As mentioned above, these earlier specimens include a male and female from 'Murray Island' housed in the NHM (the types of *T. a. zetes*, Brooks 1944) and a male also in the NHM from 'N. Queensland', the type of *T. a. queenslandicus* (Rothschild 1916). The remainder of these specimens, 5 in the AM and 7 in the MV (although Waterhouse and Lyell [1914] indicated a total of only 11) were all collected on Darnley Island (Map 1) by Hermann Elgner in 1909/10 (Moulds 1977, Dunn 2007).

In Queensland *T. a. jamesi* is primarily restricted to the islands in the northern and eastern sectors of Torres Strait, and is known with certainty from one female collected from Lockerbie at Cape York (Johnson and Johnson 1991, Braby 2000) (Map 1). The female specimen purportedly collected at Bamaga at Cape York in October 1980 by the late F.G. Sattler (now in the S. Ginn collection, Sydney) mentioned in Braby (2000) appears to be mislabelled and likely originated from Mumeng in Papua New Guinea. S. Ginn (AM) has recounted the movements of Sattler over that period and

Sattler was not known to have collected at any location in Queensland north of the Claudie River, although during this same period he visited Papua New Guinea and collected other *Taenaris* specimens while there. Therefore based on this evidence, Sattler's Bamaga record for *T. a. jamesi* is almost certainly erroneous. The precise collection details for the 'historic' male specimen housed in the NHM labelled '*N. Queensland*' (Brooks 1950, Braby 2000) are unknown and it might well have originated from the area around Lockerbie. Current Torres Strait collection records indicate that *T. a. jamesi* is restricted to Murray, Darnley and Stephens Islands in the very east of the strait, and to Saibai and Dauan Islands in the north, close to the southern coast of the Western Province of Papua New Guinea (Map 1). Interestingly, there has been only one Darnley Island specimen (1♂, 6-12.iv.1984 JWCD) of *T. a. jamesi* collected more recently than Elgner's records from a century ago, which attests to the secretive habits of these butterflies, although what is believed to be this species has been observed on the island on a number of occasions (De Baar [1988] and *unpublished data*; Johnson *unpublished data*). By far, the majority of specimens has been observed and collected from Dauan and Murray Islands.

In Torres Strait, *T. a. jamesi* is only known during the wetter months, viz. January to June. Little is known of the seasonality of the species in Torres Strait as there are no collection records for this species over dry seasons, mainly because the region is rarely visited by entomologists during the drier periods. Some correlation might be drawn from the work of Parsons (1984), who studied the ecology of *T. onolaus* Kirsch in Papua New Guinea. He found that females of this species were generally short lived and that the species was continuously brooded all year round, with large fluctuations in population numbers directly related to extremes of wet and dry periods. In addition, Parsons (1984) found that prolonged dry periods produced diapause in pupae of *T. onolaus*. Thus in Queensland *T. a. jamesi* may be continuously brooded, with populations normally increasing in numbers during the wet season.

In Australia, *T. a. jamesi* has been observed in dense primary or secondary vine thicket often with a prominent *Pandanus* S. Parkinson (Pandanaeae) component (Johnson and Johnson 1991). In Torres Strait, many specimens have been collected quite close to habitation, in the understorey of vine thicket, under mango trees (*Mangifera indica* L., Anacardiaceae) or in overgrown or abandoned banana (*Musa* spp, Musaceae) gardens. When flying in dense vegetation, they are especially adept at weaving through undergrowth and between tree trunks which makes them difficult to capture. On Murray and Dauan Islands females have also been observed swiftly traversing open ground such as over roads, between two and four metres above ground level. The species is most easily collected while resting on foliage or imbibing from over-ripe or fermenting fallen fruit and are most often only observed following disturbance from their perching or imbibing

sites. Recorded adult fruit hosts in Torres Strait are *Ficus* L. (Moraceae), *Terminalia catappa* L. (Combretaceae), *Musa* L. (Musaceae) and *M. indica*. Fruit feeding by adult butterflies on Dauan Island has frequently been observed in the mornings at around 0800hrs EST and just prior to dusk, after 1730hrs EST. Johnson and Johnson (1991) recorded *Pandanus* as a larval host for *T. a. jamesi* from material they collected on Murray Island, Torres Strait, while in Papua New Guinea, Parsons (1984) and Merrett (1996) recorded *P. odoratus* Ridl. and *Cocos nucifera* (L.) (Arecaceae) as hosts.

***Taenaris catops turdula* Fruhstorfer, 1914**

(Fig. 9)

Material examined or reviewed. QUEENSLAND (TORRES STRAIT): ♀, Darnley Island, 13.v.1910 HE (AM); ♀ same data except 18.v.1910 (MV); ♀, Saibai Island, 1.iii.1996 TAL (TLIKC).

Taenaris catops (Westwood, 1851) is known from Gebe, Waigeo, Misool, Aru, Salawati, Mioswaar, Roon, Japen, mainland New Guinea, Torres Strait and various outlying islands of Papua New Guinea (Brooks 1950, Parsons 1998). The type locality for *T. catops* is Aru (Brooks 1950, Parsons 1998). Despite it being the most widespread and the most frequently encountered *Taenaris* species in New Guinea (Brooks 1950, Parsons 1984), there are still only three specimens known from Torres Strait (Waterhouse and Lyell 1914, Braby 2000), i.e. from Darnley and Saibai Islands (Waterhouse and Lyell 1914, Braby 2000) (Map 1). These three specimens are similar in facies, being predominantly white with a pair of ocelli on each hindwing (Fig. 9). Based on the pale colouration of the two Australian specimens (Waterhouse and Lyell 1914) known to Brooks (1950) at that time, he tentatively assigned them to *T. c. turdula*, which is principally found in the southern provinces of Papua New Guinea; the type specimen being from Yule Island, Papua New Guinea. Therefore its distribution encompasses the Western Province of Papua New Guinea which is a very short distance from Saibai Island. The Saibai Island specimen collected in March 1996 is also pale and was subsequently assigned to *T. c. turdula* by Braby (2000). Nothing is known of the habits, biology or seasonality of *T. c. turdula* in Torres Strait except that the specimen from Saibai Island was collected in March 1996 as it flew swiftly, about two meters above ground level along the landward side of mangroves. In Papua New Guinea, larvae of *T. c. turdula* feed on a range of host plants, *Cordyline terminalis* (L.) (Liliaceae), *Phaius tancarvilleae* (Banks ex L'Her.) Blume (Orchidaceae), *Musa* sp., *Areca catechu* L. and *Caryota rumphiana* (Arecaceae) (Parsons 1984, 1998). Despite the paucity of material collected from Torres Strait, it is possible that the species locally occurs on Darnley and Saibai Islands, as both are largely unexplored, have potential host plant species and are infrequently visited by butterfly collectors. In addition, it is possible that *T. c. turdula* in Torres Strait might not readily frequent areas near habitation, which might explain its apparent scarcity in Torres Strait compared to *T. a. jamesi* (although *T. catops* has

been collected in gardens on the edge of villages in Papua New Guinea, T.L. Fenner, *unpublished data*).

***Taenaris myops kirschi* Staudinger, 1887**

(Figs 6-8, 10)

Material examined. QUEENSLAND (TORRES STRAIT): 4♂♂, Dauan Island, 23.ii.2006 (♂), 24.ii.2006 (♂), 6.iii.2006 (♂), 10.iii.2006 (♂) AIK (TLIKC). PAPUA NEW GUINEA: 1♀, Lae, 14.vi.1951, WWB, ID by WWB (ANIC); 1♀ same data except 6.ix.1951, determined TLF 1975; 1♀, Angoram (Sepik District) 20 ft, 26.iv.1950, WWB, ID by WWB (ANIC).

The distribution of *T. myops* (C.&R. Felder, 1860) includes Waigeo, Misool, Aru, Salawati, Mioswaar, Biak, Japen, mainland New Guinea and various islands outlying Papua New Guinea (Brooks 1950, Parsons 1998). The type locality is Aru (Brooks 1950, Szent-Ivany and Barrett 1956). Parsons (1998) described *T. myops* as being widespread in Papua New Guinea with the race *T. m. kirschi* principally occurring along the southern coast, which includes the Western Province, directly opposite and very close to the northern Torres Strait islands. The type locality of *T. m. kirschi* is Port Moresby, Papua New Guinea (Parsons 1998). In Papua New Guinea it primarily occurs in the central district of Papua in eucalyptus savannah and monsoon forest (Szent-Ivany and Barrett 1956). As its distribution encompasses the area of Papua New Guinea adjacent to Torres Strait, it is not surprising that four males of *T. m. kirschi* were collected (AIK) on Dauan Island in February and March 2006 (Map 1). My placement of these specimens into subspecies *kirschi* is based solely on geographical grounds. The four specimens were all collected, together with *T. a. jamesi*, as they imbibed on fermenting mango fruit under mango trees at the village edge. No further specimens have been observed on Dauan Island since, despite visits by a number of butterfly workers. Therefore it is unknown whether *T. m. kirschi* is resident on the island or whether it sporadically invades from the Papua New Guinea mainland, although the latter seems improbable as *Taenaris* spp are generally secretive and of a frail nature, and are mostly reluctant to fly great distances. At Port Moresby in Papua New Guinea, larvae of *T. m. kirschi* were recorded feeding on *Musa* spp. (Szent-Ivany and Barrett 1956).

***Elymnias agondas melanippe* Grose-Smith, 1894**

(Fig. 14)

Material examined. QUEENSLAND (TORRES STRAIT): ♀, Dauan Island, 4.iv.2009 MDB (MDBC).

Elymnias agondas (Boisduval) occurs to the west of New Guinea (Seram, Waigeo, Aru and Salawati), throughout mainland New Guinea, including some of its islands as *E. a. melanippe*; and into the northern coastal area of Cape York Peninsula, Queensland as *E. a. australiana* Fruhstorfer (Parsons 1998, Braby 2000). It is found primarily in or near rainforest where its host plants *Calamus* spp (rattan or lawyer palms: Arecaceae) mostly grow

(Braby 2000). *E. a. melanippe* predominantly occurs in Papua New Guinea and on its islands, Normanby, Woodlark and Daru (Parsons 1998) and its type locality is indicated as 'German New Guinea' (Parsons 1998). The species was not known from Torres Strait until April 2009 when a female of *E. a. melanippe* was collected by M. De Baar on Dauan Island, Torres Strait (Map 1) as it flew close to the village edge, near monsoonal vine forest. This specimen constitutes the first Australian record of *E. a. melanippe* and the first record of *E. agondas* in Torres Strait. The specimen collected was of the form that resembles *Taenaris* (Fig. 14), the same form that Parsons (1998) reported as a 'mimic' of various *Taenaris* species throughout New Guinea. Although *Calamus* spp have not been observed on Dauan, other Arecaceae occur naturally on the island (e.g. *Nypa fruticans* Wurmb., *C. nucifera* and *Ptychosperma macarthurii* H. Wendland)

***Papilio aegeus ormenus* (Guérin-Ménéville), 1831**

form *ormenus* Guérin-Ménéville variety *onesimus* Hewitson, 1858

(Figs 15, 16)

Material examined. QUEENSLAND (TORRES STRAIT): 1♀ Dauan Island, 11.v.2001 AIK (TLIKC); 2♀♀ same data except 6.i.2006, 5.iv.2009 TAL; 1♀ same data except 1-8.iv.2009 MDB (MDBC); 1♀ Darnley Island, 1-2.iv.1987 MDB (MDBC); 1♀ Murray Island, 1.v.1999 AIK (TLIKC); 1♀ same data except (Mer), 29.iii.-4.iv.1986 MDB (MDBC); 1♀ Moa Island (St Pauls Mission), 10-16.ii.1986 KH & EH (QPIFC).

Papilio aegeus Donovan occurs across Torres Strait as two subspecies, demarcated roughly in the central area of the strait, with the nominate race, *P. a. aegeus* Donovan found on and south of the central island group (Moa, Badu and Maubiag Islands) and *P. a. ormenus* predominantly occurring north and east of this group, although specimens considered to be *P. a. ormenus* are also known from the central island group (Map 1). Braby (2000) regarded the central area of Torres Strait to be a hybrid zone for the two subspecies, and indicated that some specimens from this central island group can be variable, possessing intermediate characters and consequently are difficult to place. In general, the females of both subspecies can be highly polymorphic, particularly so for *P. a. ormenus* and especially in Papua New Guinea (Parsons 1998). Hancock (1983) reviewed the systematics and biogeography of *P. aegeus* (as *Princeps aegeus* [Hancock 1983]) and concluded that there were primarily three female forms of *P. a. ormenus*, of which one form, *ormenus* Guérin-Ménéville, variety *onesimus* Hewitson is a pale *Taenaris*-like morph with white forewings and darker costal and apical borders (Figs 15, 16). Similarly Braby (2000) reported three forms in general for *P. a. aegeus*, with form *beatrice* Waterhouse being roughly analogous to the more northern *ormenus* form of *P. a. ormenus*, although a true *Taenaris*-like form (strictly comparable to variety *onesimus*) is not known within females of *P. a. aegeus*.

Discussion

Parsons (1991, 1998) and D'Abrera (1978) emphasised the extreme variation within *T. artemis*, *T. catops* and *T. myops*, and because of this variation, Parsons (1998) considered that Brooks (1950), in his review of *Taenaris*, could not justify listing 20, 26 and 13 subspecies respectively of such variable taxa. Parsons (1998) reviewed *T. artemis* across its range and due to its variability he accepted only six subspecies for Papua New Guinea, and even placed some doubt on the validity of these six, still referring to them as 'supposed'. In Australia, because of this variability, Wood (1987) and Braby (2000) consequently treated *T. a. zetes* Brooks from Murray Island, Torres Strait and *T. a. queenslandicus* Rothschild from north Queensland as junior synonyms of *T. a. jamesi*. Additionally, Parsons (1998) recognised only 11 subspecies of *T. catops* and just three *T. myops* subspecies from Papua New Guinea.

In support of his own review of the above three species and their subspecies, Parsons (1998) indicated that 'Müllerian mimetic associations' and 'the existence of clinal variation' contributed to the variability shown by these species throughout their range. Parsons (1991, 1998) indicated that the variation in their facies was ostensibly influenced by the overall similar facies of their mimetic *Taenaris* counterparts (interspecific and intraspecific), and other mimicry 'models' occurring in the same geographical area. In addition, he proposed that this particular influence on variation even caused 'females to closely resemble their respective males at any given locality' (Parsons 1991). Moreover, Brooks (1950) who first reviewed the genus also suggested that *T. myops* and *T. artemis* 'both conform to a typical geographical pattern'. Therefore, Parsons (1998) considered that mimetic and clinal influences on local populations, combined with an overall degree of natural variability of these three species justified his reluctance to adopt many, if not all of the geographical races, in particular those of *T. artemis*.

Despite Brooks (1950) and Parsons (1998) proposing that mimicry and clines might strongly influence the variation observed in *Taenaris* species, Szent-Ivany and Barrett 1956 found that the many individuals of *T. myops* that they reared on banana at Port Moresby, Papua New Guinea showed high variability in the extent of wing colouration and in the size of the ocelli. Similarly in Torres Strait, *T. a. jamesi* and *T. m. kirschi* are highly variable (Figs 1-8), even in series of specimens from small islands such as Dauan. Thus, this high degree of variation recorded in confined geographical areas such as Dauan Island places some doubt on the proposition by Parsons (1991, 1998) and Brooks (1950) that mimicry and clinal variation could strongly influence the variability of these two species.

Identification of the three *Taenaris* species that occur in Torres Strait is mostly easy, and males in particular of each species can be clearly delineated, more so than the females. Males of *T. catops* have typically short, stubby

forewings (the wings are almost square in cross section), prominent dark scaling along the radial, medial and cubital veins of the forewing upper (Parsons 1998), and the forewing inner margin is always devoid of dark scaling (which the other two species almost always have) (Parsons 1998). In addition, both sexes of *T. catops* can be easily separated from other members of the genus by the position of hindwing ocelli, which in *T. catops* is set in further from the termen in the subterminal area, while in other *Taenaris* species, the ocelli sit in the tornal area of the hindwing (Waterhouse and Lyell 1914). *Taenaris myops* males always possess dark androconial scales underlying the inner marginal hair-streak on the hindwing upper (Brooks 1950, Parsons 1998) (Figs 6-8), while Parsons (1998) indicated that the males of *T. artemis*, in addition to lacking the androconial inner marginal scales of *T. myops*, are generally paler and more tan-brown to grey-brown in colour as opposed to the dark brown, almost black markings of *T. myops*, although some individuals of *T. a. jamesi* from Torres Strait can have grey-black colouration (Fig. 5). Moreover, specimens of *T. a. jamesi* known from Torres Strait are highly variable in wing colouration, extent of colouration and wing shape (Figs 1-5).

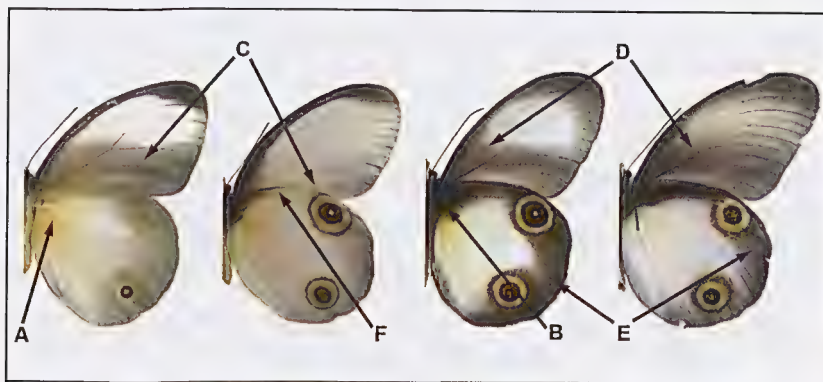


Fig. 17. Principal wing features (not including dark androconial scales) considered useful by Brooks (1950), D'Abrera (1978) and Parsons (1991, 1998) (see Discussion) in identifying *Taenaris artemis jamesi* and *T. myops kirschi*. All figures not to scale [forewing lengths, in mm, in square brackets]. A: yellow basal area of upperside hindwing; B: hindwing costal border not terminating at wing base; C: position of forewing inner margin; D: forewing cell; E: dark-brown almost black markings; F: absence or reduction of hindwing costal border. Specimen data, left to right: *T. a. jamesi* female upperside, Dauan Island, 9.iii.2006 [57], AIK; *T. a. jamesi* female underside, Dauan, 6.iii.2006 [54], AIK; *T. m. kirschi* male underside, Dauan, 24.ii.2006 (49), AIK; *T. a. jamesi* male underside, Dauan, 9.iii.2006 [47], AIK.

Among the females of the three *Taenaris* species in question, only the female of *T. catops* (Fig. 9) can be reliably identified (see above). A number of workers have attempted to separate females of *T. artemis* and *T. myops* on the

basis of wing colouring. Brooks (1950) indicated that the female of *T. artemis* could often be distinguished from allied species by the presence of a yellow area below the base of the upperside hindwing (Fig. 17A), and dark forms of *T. myops* could be separated from allied dark forms by the costal border of the hindwing underside not terminating at the wing base but expanding around into the hindwing (Fig. 17B). In addition Brooks (1950) reported that the overall markings of *T. artemis* tend to be 'light' in colour. Finally in his review of the genus he summarised the difficulty in reliably separating the two species and stated that the 'females of some of the races of *T. artemis* and *T. myops* so closely resemble each other that it is impossible to describe characters which separate them'. D'Abrera (1978) listed two characteristics that he considered peculiar to female *T. artemis*, the first was the top edge of the forewing band in the inner marginal space which, when present, is more or less parallel with the dorsum (Fig. 17C), and secondly, where the marginal band enters the cell it never completely fills it but leaves a lighter space that more or less follows the shape of the vein which closes off the cell (Fig. 17D). Parsons (1991) considered that *T. artemis* could be distinguished from *T. myops* by its paler colour, 'more tan-brown compared to the dark-brown, almost black markings of *T. myops*' (Fig. 17E), (even though some individuals of *T. a. jamesi* from Torres Strait can be almost black in colouration Fig. 12), and in *T. artemis* by the colour not fully filling the forewing cell (Fig. 17D), whereas it does in *T. myops*. Later, Parsons (1998) reported that the yellow sub-basal area of the upper side hindwing of *T. artemis* (as Brooks [1950] reported) (Fig. 17A) was not a useful character to distinguish *T. artemis*, as the hindwing of *T. myops* is also frequently sub-basally yellow. Nonetheless, Parsons (1998) regarded the most useful characters that distinguish females of *T. artemis* from females of *T. myops* were the narrower dark brown forewing inner marginal band (or absence of forewing inner marginal band) of *T. artemis* (Fig. 17C), and the hindwing inner margin of *T. myops* being narrowly bordered with dark brown (Fig. 17B), but usually completely white in *T. artemis* (Fig. 17F).

Accordingly, using information provided by Brooks (1950), D'Abrera (1978) and Parsons (1991, 1998), my assessment of the female *Taenaris* specimens reviewed in this paper, predominantly from Torres Strait, and of a small series of six female *Taenaris* from southern Papua New Guinea, purportedly identified as *T. a. jamesi* and *T. m. kirschi* (ANIC), places doubt on the reliability of many if not all of the above characters when used to separate either sex of the two species. Based on my assessment I found no helpful, consistent or reliable characters (as illustrated in Fig. 17) that could be dependably used to identify females of the two species (including the six specimens from Papua New Guinea). In effect, for pale morphs of both species, even male specimens would be difficult to distinguish using only these characters. Based on this, and the fact that only four out of a total

of 39 male *Taenaris* specimens collected on Dauan Island are *T. m. kirschi*, I have tentatively classified all females specimens examined from Dauan Island and the remainder examined from Saibai, Darnley and Murray Islands, including the specimen from Lockerbie as *T. a. jamesi*.

The reporting here of female *P. aegeus ormenus* form *ormenus*, variety *onesimus* from Torres Strait constitutes the first recognition of this *Taenaris*-like variety from Australia and here, two specimens are first illustrated from Torres Strait. Moreover, due to the intensity of butterfly collecting undertaken on Dauan island since the early 2000s it seems likely to surmise that the first capture of *E. a. melanippe* on the island in April 2009, in conjunction with the specimen being quite worn, likely constitutes a vagrant from nearby Papua New Guinea. In addition, because of the capture of four relatively fresh specimens of *T. m. kirschi* from Dauan Island in 2006 and none since, it might be possible that vagrant populations of this species from Papua New Guinea from time to time may become established on Dauan Island. Conversely, due to the fragility of *Taenaris* butterflies and their sedentary behaviour, and the fact that many Torres Strait islands (Map 1), including Dauan, are still largely unexplored because of the nature of their terrain, it is feasible that *E. a. melanippe* and *T. m. kirschi* might be established on Dauan Island.

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THE AESTIVATION SITES OF BOGONG MOTHS, *AGROTIS INFUSA* (BOISDUVAL) (LEPIDOPTERA: NOCTUIDAE), IN THE SNOWY MOUNTAINS AND THE PROJECTED EFFECTS OF CLIMATE CHANGE.

KEN GREEN

*Snowy Mountains Region,
NPWS, PO Box 2228, Jindabyne, NSW 2627.
(email: kenneth.green@environment.nsw.gov.au)*

Abstract

Bogong moths constitute a keystone species in the ecology of the alpine zone of mainland Australia with an estimated 2.2 billion moths migrating to the Snowy Mountains annually. During spring they are found in temporary camps and in aestivation sites in boulderfields and among complex rock tors, with most moths moving to the higher altitude sites as summer progresses. Aestivation sites have a higher relative humidity than in nearby meteorological screens but similar temperatures. Crevices in boulderfields and among rock tors are open to heat exchange with the atmosphere during the summer and consequently their temperatures fluctuated in step with the fluctuations in the screens, but with the dampening of extremes in the aestivation sites. This meant that the average daily temperature in aestivation sites falls with increasing altitude at about 0.7°C per hundred metres of ascent, which approximates the regional lapse rate. As a consequence, questions about the future viability of aestivation sites for bogong moth populations (and that of their obligate parasites and predators) under a future climate change scenario can be answered from general climate models.

Introduction

Larvae of bogong moths *Agrotis infusa* (Noctuidae) feed in the western plains of eastern Australia from the Darling Downs in Queensland, south to the north-western plains of Victoria (Fig. 1). There is no regular monitoring of numbers of larvae despite their occasional outbreaks as pests, when they are believed to damage winter cereal crops (Gregg *et al.* 1994). The moth can be a univoltine or bivoltine species, with the cutworm larvae feeding on annual plants which are unavailable over summer. Because of this, most of the adults of the spring generation migrate to aestivate gregariously in the Australian Alps (Common 1954). The numbers of moths involved in this annual migration are not known, but Green (2010) calculated that total annual mortality of moths in the 1400 km² above 1500 m asl in the Snowy Mountains from predation, and non-predator-related causes such as parasitism and weather amounted to 1015 million moths. These contributed approximately 5000 GJ of energy annually together with 7 t of nitrogen and 1 t of phosphorus to the mountains, emphasising their importance as a keystone species in the ecology of the alpine zone.

A key to our understanding of the ecology of bogong moths in an uncertain climatic future is their summer distribution. Common (1954) tracked the changes in numbers at one site and recorded regularly used aestivation sites in the Brindabella Ranges. There are also a number of anecdotal records of locations and Common (1954) suggested that the frequency of the word 'bogong' in place names meant that sites where bogong moths congregated

were likely to be quite common. The present study set out to examine the distribution of sites used by bogong moths in the Snowy Mountains above 1500 m asl (Fig. 2). This area is important because it contains the highest known sites and hence the ones least likely to be rendered unsuitable by climatic warming. A further aim was to examine the characteristics of sites to test their resilience in the face of future warming.

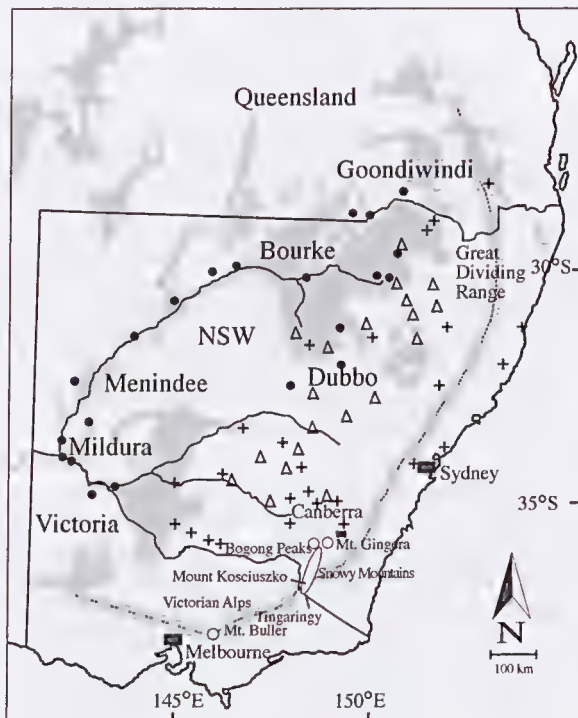
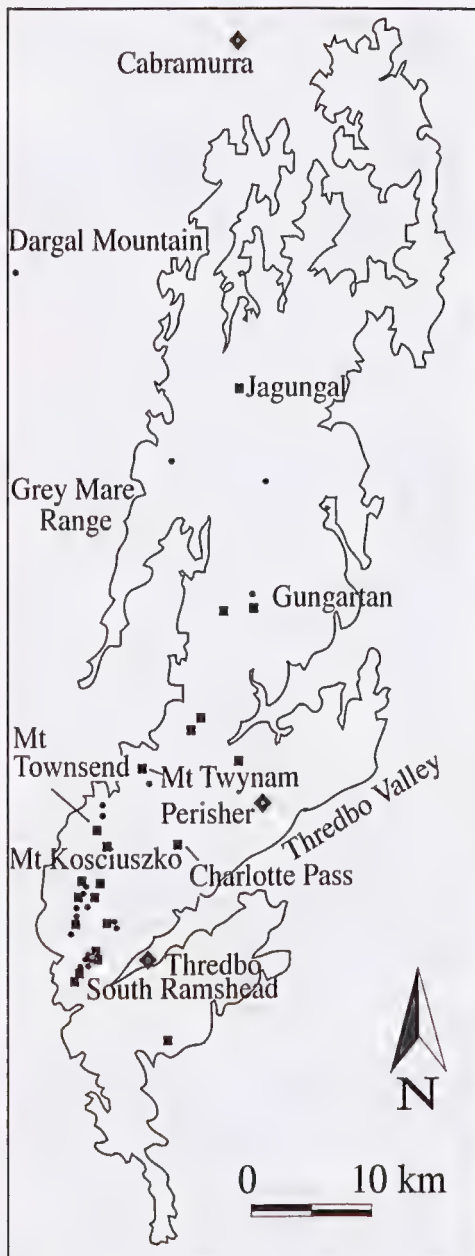


Fig. 1. Map of south-eastern Australia showing the self mulching soils (shaded) which are thought to be the important breeding areas for bogong moths, together with locations where larvae were collected by Froggatt (1900) (open triangles), Common (1954) (crosses), Green (2008) (closed circles), and the sites outside of the Snowy Mountains mentioned in the text. (After Common 1954).

Methods

Distribution of moths

In the summers of 2000/01 through to 2009/10, all large complex rocky outcrops, blockstreams and blockfields in the Snowy Mountains above 1500 m asl were searched for evidence of bogong moths. Sites were visited on foot with a final survey by helicopter to ensure that no obvious sites were missed. Sites in the present study were recorded as either an aestivation site used in



high summer or temporary camps, following the classification of Common (1954) of 'camps' and temporary camps. Locations of sites were recorded with a hand-held GPS. The aspect of the aestivation crevices was recorded using a hand-held compass.

Statistical examination of the aspect was undertaken using the Rayleigh test (Batschelet 1981).

Movement of bogong moths out of temporary camps and into the higher aestivation sites is difficult to map because it is difficult for a person to observe inside most bogong moth sites. However, foxes are much smaller, and are driven by their need for food, so examination of their scats at different altitudes facilitated this monitoring. A study of fox diet on alpine and subalpine transects was undertaken from January 1996-December 1998 by collecting scats monthly (Green 2003). The composition of scats was studied and the proportion of bogong moths present in them was determined for two complete

Fig. 2. Map of the contiguous area above 1500 m altitude in the Snowy Mountains showing moth aestivation sites (squares) and temporary camps (closed circles).

summer seasons, 1996/97 and 1997/98. These data were plotted to examine the relative abundance of bogong moths monthly at different altitudes.

Temperature and relative humidity

Temperature loggers and temperature/RH loggers (Tinytag plus and Tinytag Extra -Gemini Data Loggers, Chichester England) were deployed from 2001 onwards in a number of bogong moth camps and caves. Loggers were placed above ground level in free flowing air in areas where moths congregated. This was confirmed when moths were disturbed from behind the loggers at a number of sites when the loggers were retrieved.

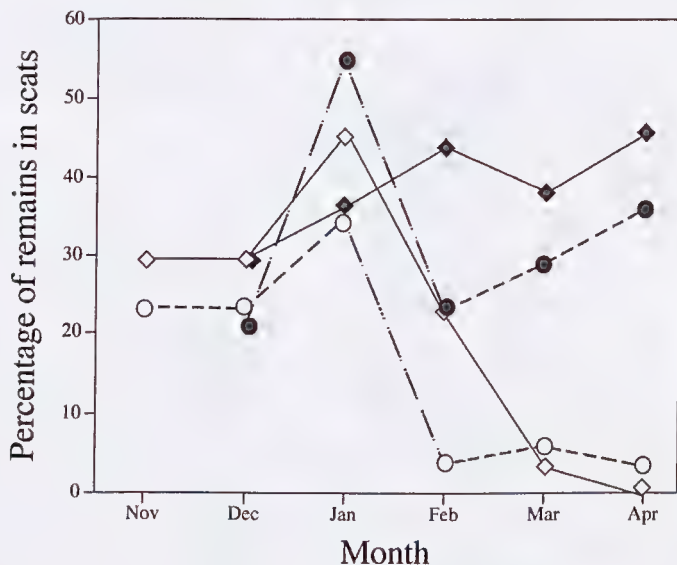


Fig. 3 Mean proportion of individual fox scats occupied by bogong moth remains at subalpine (open symbols) and alpine altitudes (closed symbols) over two summer seasons, 1996/97 (solid lines; diamonds) and 1997/98 (broken lines; circles).

Results

Distribution of moths

Within the study area in the Snowy Mountains there were 92 bogong moth temporary camps and 42 aestivation sites (Fig. 2). Outside the study area, bogong moth aestivation sites were found in isolated sites at Mt. Tingaringy (37° 00'S, 148° 40'E) to the south-east of the Snowy Mountains on the Victorian Border, at the Bogong Mountains to the north-west, and on the peaks constituting the border with the Australian Capital Territory to the north east (Fig. 1), with a camp on Dargal Mountain (Fig 2). Most bogong moth sites were found along the highest ridge-line of the Kosciuszko Main Range, with a group of outliers around Gungahlin and mainly individual

outliers elsewhere. Sites were generally complex rock tors or periglacial boulderfields and boulderstreams. Elsewhere, where rock outcropping was rare, for example to the north of Jagungal and southwest along the Grey Mare Range, there were no sites. The Crackenback Range, running along the northwestern side of the Thredbo Valley from east of Perisher Valley through to the South Ramshead contained outcroppings along the edge of the steep drop-off to the Thredbo Valley. Many of these outcroppings appeared suitable as aestivation sites or at least camps, but held no evidence of present or previous occupation by bogong moths.

The aspect of the aestivation sites was dependent upon geomorphology and the alignment of suitably exposed fragmented rock. For the test of preferred aspect, the relevant statistic for the Rayleigh test is w . If $w > 3.0$, then the null hypothesis of no clumping of bearings would be rejected. For the aestivation sites $w = 0.138$, and for the temporary camp sites $w = 1.792$. Thus both null hypotheses of no clumping were accepted. Because of the lack of clumping the calculation of mean bearing is meaningless.

No fox scats were collected in the alpine zone in November because, with melting snow still on the transect, their date of deposition (winter or spring) could not be ascertained. Bogong moth remains in scats peaked in January, thereafter there was a general decline during February (which at the Thredbo Automatic Weather Station has the highest mean maximum and minimum temperatures and is also the driest month). After February, bogong moths were not common in scats at subalpine altitudes but increased in frequency in scats at alpine altitudes (Fig. 3)

Temperature

At Charlotte Pass (1755 m asl), over the period November 2009 to March 2010, the average temperature in the boulder field ($12.3 \pm 2.9^\circ$) was not significantly different ($t = 0.787$, $df = 118$, $p = 0.433$) from that in the Bureau of Meteorology Stevenson Screen ($12.2 \pm 3.4^\circ$). However, at the South Ramshead site (1950 m asl) over the period December to March, the temperatures in the cave and Stevenson Screen were significantly different in both 2002/03 ($t = 2.849$, $df = 95$, $p < 0.01$) and 2003/04 ($t = 4.692$, $df = 106$, $p < 0.0001$). Though significant, this may not be biologically important with the temperature in the cave differing little from that in the Stevenson Screen in 2002/03: $11.9 \pm 3.5^\circ$ against $12.2 \pm 4.4^\circ$, and in 2003/04: $10.7 \pm 3.6^\circ$ against $11.2 \pm 4.3^\circ$. Corrected for a temperature lapse rate of 0.77°C per 100 m (Galloway 1988), these differences would be equal to a difference in altitude of 40 and 65 m respectively.

Over the period November 2009 to March 2010, there was a significant difference ($t = 16.843$, $df = 104$, $p < 0.0001$) between temperatures at the Charlotte Pass Stevenson Screen ($12.3 \pm 3.5^\circ$), and the bogong moth

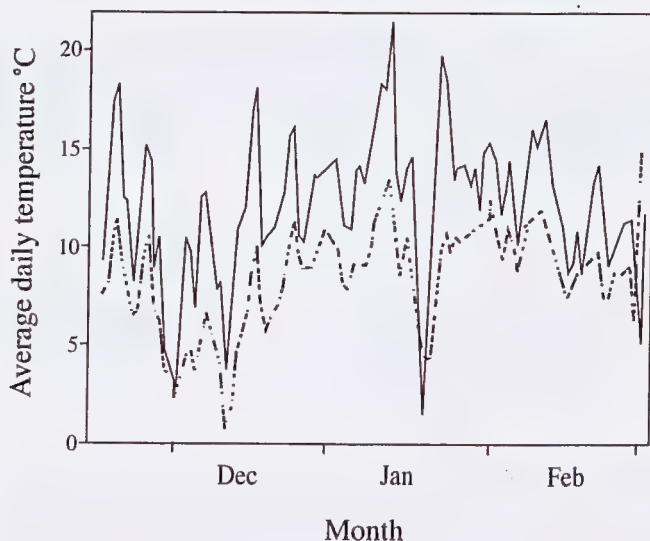


Fig. 4 Average daily temperatures over the period November 2009 to March 2010 in the Bureau of Meteorology Stevenson Screen at Charlotte Pass, 1755 m (solid line) and the bogong moth aestivation site on Mt Kosciuszko, 2210 m (broken line).

aestivation site on Mt Kosciuszko at 2210 m asl ($8.6 \pm 2.5^\circ$). Although these were significantly different, the plot of the two locations suggests that the two were following the same general weather patterns (Fig. 4), with differences mainly related to the air temperature lapse rate. In fact, when all locations were plotted there was a highly significant negative relationship between average temperature and altitude ($r^2 = 0.943$, $p < 0.0001$) (Fig. 5), and the expression $(0.0068x)$ in the equation of the line $y = -0.0068x + 24.278$ closely approximated the expected lapse rate of $0.0077x$ where x is the altitude in metres (Galloway 1988).

The winter temperatures showed differences between sites among rock tors on the South Ramshead and in boulderfields on the flanks. In the period leading into the full winter snowcover, the sites fluctuated in reasonable synchrony (Fig. 6). However, once the snowcover blanketed the boulderfields the air space between boulders was disconnected from the ambient air and in the second half of winter there was no fluctuation in the temperature trace.

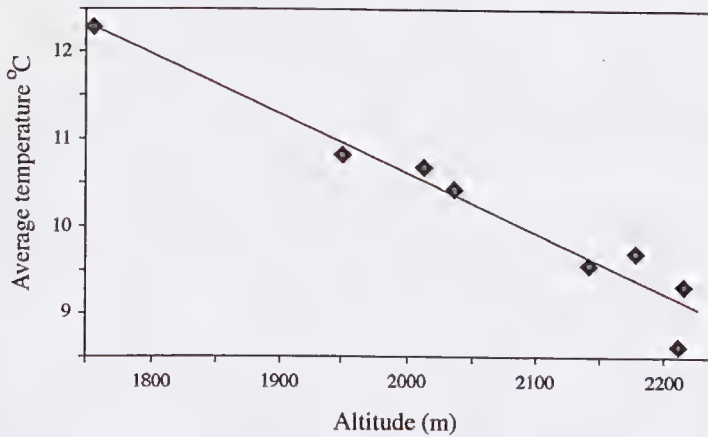


Fig. 5 Regression of average daily temperature from November 2009 to March 2010 in bogong moth aestivation sites on altitude. The formula of the line is $y = -0.0068x + 24.278$.

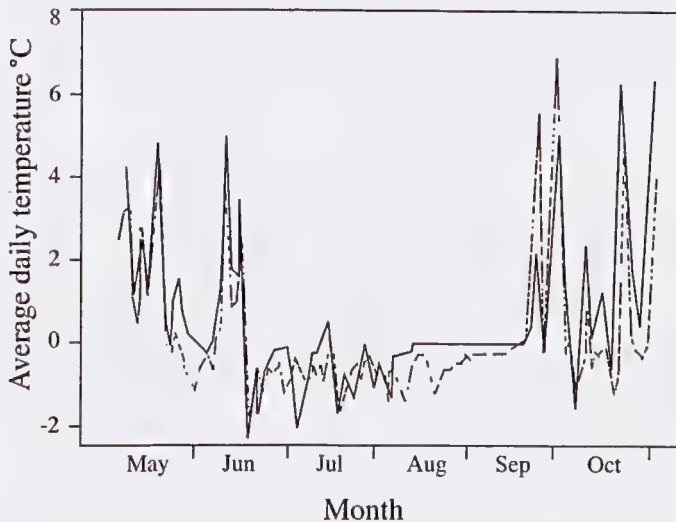


Fig. 6 Average daily temperatures in a boulderfield at 1950 m (solid line) and rock tors at 1515 m (broken line) on the South Ramshead over the period when obligate parasites of bogong moths are independent of their hosts

By contrast, because of the architecture of the upright boulders in the tors, there was no such disconnection in the sites in these tors. Summer temperature data from the north and south aspects of the South Ramshead and Mt Townsend showed opposite trends. For South Ramshead, the bogong

moth caves on the northerly aspect were warmer ($10.7 \pm 3.5^\circ$) than the south facing caves ($10.4 \pm 3.4^\circ$), a significant difference ($t = 2.200$, $df = 104$, $p < 0.05$). By contrast, for Mt Townsend the bogong moth caves on the southerly aspect were warmer ($9.5 \pm 3.1^\circ$) than the north facing caves ($9.3 \pm 3.4^\circ$), again a significant difference ($t = 2.174$, $df = 104$, $p < 0.05$). However, there were slight altitudinal difference between the sites on north and south (80 m for Mt Townsend and 25 m for the South Ramshead) and when this was corrected for using a lapse rate of 0.77° per 100 metres (Galloway 1988), there was no significant difference between aspects on the South Ramshead ($t = 433$, $df = 104$, $p = 0.666$) whereas on Mt Townsend the northerly aspect was significantly warmer than the south ($t = 5.301$, $df = 104$, $p < 0.0001$).

Relative humidity

Over the period November 2009 to January 2010, there was a significant difference ($t = 3.621$, $df = 51$, $p < 0.001$) between mean daily relative humidity at the Charlotte Pass Stevenson Screen ($64.5 \pm 15.2\%$), and the boulderfield moth aestivation site at the same location ($70.2 \pm 17.3\%$). Over the period November 2009 to March 2010, there was a significant difference ($t = 11.738$, $df = 71$, $p < 0.0001$) between mean daily relative humidity at the Charlotte Pass Stevenson Screen ($66.7 \pm 14.2\%$), and the moth aestivation sites at Mt Townsend ($75.9 \pm 14.4\%$), a similar figure to that recorded on the South Ramshead northerly aspect cave from November 2001 to March 2002 ($75.3 \pm 14.4\%$).

Discussion

Distribution

The apparently suitable but unoccupied rock outcrops on the Crackenback Range may reflect a preference by bogong moths for higher, cooler sites, even though moths were found elsewhere at lower altitudes such as at about 1200 m on the north side of Mt Tingaringy. However, it might also be possible that along the length of the Crackenback Range, until South Ramshead is reached, most of these sites have rolling terrain to the north and west and the outcrops are not distinct landmarks except from the south. If moths find the sites visually these might not stand out on dark nights. The whole question of how bogong moths find their chosen sites and the roles and relative importance of visual and olfactory cues is one that requires some attention.

Common (1954) found large aggregations on south-western slopes and none on apparently suitable sites on north-easterly slopes, and Blakers (1980) suggested that aestivation sites were preferentially located on the south side of peaks. Common (1954) did speculate that the chosen aspect in the Brindabellas may be a result of the availability of outcrops and the present study showed that throughout the Snowy Mountains overall, there was no fixed aspect on which bogong moths congregated. The location of aestivation

sites and camps was more a result of geomorphology than choice of aspect. The preference for higher sites, when available, appears to occur seasonally, where through incremental upwards movement, or because more room becomes available due to attrition of populations over the summer period through mortality or migration, moths moved to higher aestivation sites particularly from February onwards.

Numbers

There has been little information on the summer distribution of bogong moths in the past, outside of the Brindabella Range (Common 1954). The difficulties in calculating total numbers in aestivation sites from the unknown proportion that are visible, means that there have been no attempts to date to calculate a total number of bogong moths migrating annually. From a process of allocating mortality between predation, parasitism and weather-related mortality, Green (2010) calculated a total mortality of 985 million bogong moths in the Snowy Mountains annually. Blakers (1980) estimated that in a 'good year' for moth numbers there would be a 45% reduction in numbers of bogong moths while in aestivation sites. Based on this, a first order estimate of the number of moths migrating to the Snowy Mountains annually would be 2.2 billion. Allowing for early season mortality of about 285 million moths, when moths were mainly occupying camps (Green 2010), the estimated number of bogong moths in the Snowy Mountains at its peak (around 1 January, see Common 1954), would be about 1.9 billion moths. At a density of 17 000 moths m⁻² (Common 1954) this would require 112 000 m² of usable rock face in the main aestivation sites at peak abundance. If these were spread evenly across the 42 aestivation sites recorded here, there would be about 45 million moths per site. On the wall of Common's observation cave were an estimated 144 000 moths (Common 1954). Bennett (1834) stated that, 'the quantity of moths which may be collected from one of the granite groups, it is calculated would amount to at least five or six bushels' (180-220 litres). This would translate to about 200 000 moths at 100 per litre. These are the figures for the easily observed (and captured) numbers and represent less than half a percent of the total calculated per site. These easily counted moths, that by definition occupy the most exposed, and possibly least preferred areas of suitable wall (Common 1954) would probably not be of great value in calculating numbers of the unknown proportion within aestivation sites. Hence the difficulties in calculating annual variation in total numbers of migrating moths appear to be intractable at present.

Temperature and relative humidity

Crevice in tors and boulder fields act like dynamic caves, that is, air flows through them as part of the general air circulation with almost instantaneous warming and cooling (Geiger 1965; Harris and Pedersen 1998). This was demonstrated for a cave on the South Ramshead, where comparisons between

logger temperatures in the boulders followed temperature recorded in a nearby Stevenson screen differing only by 0.3° through summer of 2002/03 and 0.5° in 2003/04. At the Charlotte Pass boulder fields the match was much closer (0.1°). There will be a varying relationship between measured temperatures, perhaps dependent on the exact placement of the loggers that cannot be standardized in the same way as measurements in a Stevenson screen. Regardless of this, as temperatures fell with altitude so did the temperatures in aestivation sites, and at about 0.7°C per hundred metres of ascent it fell at close to the lapse rate calculated by Galloway (1988).

More uniform temperatures and higher humidity are characteristic of caves (Geiger 1965). Relative humidity in caves in the present study also changed with the general air circulation patterns, rising and falling with that recorded in a meteorological screen. However, the relative humidity in caves was about 10% higher in moth aestivation sites. This would probably be higher still where the moths congregate, overlapping like tiles and further restricting moisture transport to the circulating air (Common 1954). This could be important in reducing water loss by the moths during aestivation because, when moths, en masse, leave the caves to drink they may be more exposed to predators (Green pers.obs.).

Climate change

Concerns have been expressed as to the impacts of climate change on bogong moths and their predators, particularly the mountain pygmy-possum (*Burramys parvus*) (Heinze et al. 2004). The major predators on bogong moths in the Snowy Mountains are little ravens (*Corvus mellori*), bush rats (*Rattus fuscipes*), Richard's pipits (*Anthus novaeseelandiae*) and foxes (*Vulpes vulpes*) (Green 2010). Although not an important predator on the moths, *B. parvus* is the only predator that is dependent on them, in fact, high altitude populations of *B. parvus* would not survive without access to migratory bogong moths as a food resource (Heinze et al. 2004). Two species of mermithid worms that parasitise bogong moths *Amphimermis bogongae* and *Hexamermis cavicola* (Welch 1963) are also dependent on them (Common 1954). These worms emerge from the moths in January and February, causing their deaths. They remain in the caves over winter and re-infest moths in spring. For these species that remain in the moth sites, the wintering temperature is also important. In this case the temperatures in the two architectures (boulderfields and caves in tors) do not correspond as well as they do in summer. Initially, after the moths have left, temperatures are similar but as snow begins to accumulate they become disconnected, and with full snowcover the winter temperature in the boulderfields is fully disconnected from ambient temperature fluctuations and remains steady at just above 0°C (Fig. 6) while the caves in tors still maintain a connection with outside temperature because of the upright, more open, architecture. This, however, may have little impact on the overwintering worms if they are

buried deep in the moth detritus on the floor of caves, and *B. parvus* is unlikely to remain in the caves in tors over winter, probably leaving for lower altitude boulderfields once the moths have gone.

Migration accompanied by diapause may be essential for the survival of bogong moths (Common 1954). Without the refuges in boulderfields and caves, this may not be possible. The present study shows that while the bogong moths occupy the highest possible altitude within their range, and there is an upward movement through the summer season as conditions become warmer and drier, there is still some flexibility because it is the lowest altitude that they can occupy that is important in determining their requirements. While loss of some lower altitude sites may have an impact on the numbers that can aestivate, the loss of progressively higher sites with climate warming will take some time. There will be a varying relationship perhaps in different locations between temperature inside and outside of aestivation sites but, as global temperatures rise so, obviously, will the temperatures in boulderfields. Because the aestivation sites generally follow air temperature they will become unusable at the same rate as regional warming so that a worst case scenario of warming in alpine areas of 2.9°C by 2050 (Hennessy et al. 2008) will lead to a loss of aestivation sites in the lowest 400 m of their range unless moths are able to adapt. Taking the Mt. Tingaringy site (1200 m) as a possible minimum altitude for aestivation, means that most sites above 1600 m should still prove suitable for aestivation and this includes all of the sites recorded in the present study.

Conclusion

Crevice among boulderfields and rock tors provide a dark, cool, relatively stable and moist environment necessary for aestivation and the long-term survival of bogong moths in high numbers. The locations where moths congregate are far enough from the outer surface of the rocks for aspect not to be important. Because the temperature in aestivation sites is dependent on shade air temperature, higher sites are cooler in accord with the regional temperature lapse rate. Most sites used in the Snowy Mountains are above 1700 m altitude and even in a worst-case climate change scenario to 2050 should be proof against becoming unsuitable for moths.

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A REVIEW OF GYNANDROMORPHISM IN THE GENUS *ORNITHOPTERA* BOISDUVAL, (LEPIDOPTERA: PAPILIONIDAE)

J. E. NIELSEN

GPO Box 858, Canberra, ACT 2601

Abstract

A review of records of gynandromorph specimens in the genus *Ornithoptera* Boisduval is presented, with the causes of gynandromorphism in insects briefly discussed. Most *Ornithoptera* gynandromorphs are known from *O. priamus* (Linnaeus), which probably reflects the number of specimens available as opposed to an unusual tendency towards gynandromorphism in this species. Gynandromorphs are also known of *O. croesus lydius* (Felder), *O. victoriae regis* (Rothschild), *O. goliath* Oberthür, and the Australian taxa *O. priamus pronomus* (Gray), *O. richmondia* (Gray) and *O. euphorion* (Gray).

Introduction

A gynandromorph is an organism whose genotype simultaneously expresses aspects of both male and female morphology in the phenotype. Gynandromorphism is generally attributed to genetic errors associated with cell division, with different errors at different stages of development believed to produce different types of gynandromorph (Pereira *et al.* 2003, Richards and Davies 1977, Wigglesworth, 1972). Gynandromorphs are exceedingly rare in nature and are only obvious where there is strong sexual dimorphism. The phenomenon has been most commonly observed in insects, where the phenotypic expression of sexual difference is not mediated by the prevailing endocrine environment. Gynandromorphism has also been recorded in birds, where other processes have been postulated, including the suggestion that sex chromosome genes acting within individual cells directly contribute to sex differences in cell function (Agate *et al.* 2003).

The precise mechanism leading to gynandromorphism is not well understood in butterflies, in which sex is determined by a WW/WZ system, with the heterogametic sex (ie WZ) being the female, the reverse of the condition found in mammals and most other insects. It is better understood for the *horka* mutation of the vinegar fly *Drosophila melanogaster* (Meigen, 1830) (Szabad *et al.* 1995). All known mechanisms of *Drosophila* gynandromorphism rely on the zygote (fertilised egg that has not yet undergone division or cleavage) having an initial chromosome component of X^YX (male), and subsequent loss of the X chromosome.

In *D. melanogaster*, the *horka* mutation produces gynandromorphs due to nondisjunction, where chromosome inheritance to 'daughter' cells is inhibited. For *horka*, all chromosomes except X^Y are unreliably inherited during cleavage and subsequent cell divisions producing the blastula (Szabad *et al.* 1995). If the X chromosome is not inherited by one of the cells produced at cleavage, its absence will likewise be inherited by all 'daughter' cells. As the two cells produced at cleavage subsequently proliferate into what later become the lateral halves of the adult organism, this type of error

may ultimately produce a phenotype whose lateral halves are of opposite sex (bilateral gynandromorph). Localised loss of the *X* chromosome later in development is also believed to produce gynandromorphs whose phenotype is a mosaic of both male and female morphology (Richards and Davies, 1977; Wigglesworth 1972) (mosaic gynandromorphism).

Additional causes of gynandromorphism in insects include fertilisation of binucleate ova, replacement of mitotic cell division with meiosis and fertilisation by multiple sperm, which may fuse and act as a second nucleus (Pereira *et al.* 2003, Richards and Davies 1977, Wigglesworth 1972).

Gynandromorphism in *Ornithoptera*

Ornithoptera Boisduval, 1832 is a genus of thirteen species of swallowtail butterflies restricted to the Australasian biogeographic region (ie. east of Wallace's line) (Parsons 2000). Three species, *O. richmondia* (Gray, 1852), *O. euphorion* (Gray, 1852) and *O. priamus* (Linnaeus, 1758), occur within Australian territories (Braby 2000). Along with two additional genera (*Trogonoptera* Rippon, 1890 and *Troides* Hübner, 1819), the *Ornithoptera* are popularly known as birdwings and have attracted considerable scientific interest in the areas of taxonomy (e.g. Hancock 1983; 1991; Braby *et al.* 2005), conservation ecology (Collins and Morris, 1985, Sands *et al.* 1997, Sands and New 2002) reproductive biology (Orr, 1988) and general ecology (Matsuka 2001, Parsons 2000). As this genus includes some of the largest and most spectacular of all Lepidoptera, they are much prized by amateur collectors (Collins and Morris, 1985). All species (excluding *O. alexandrae* (Rothschild, 1907)) are presently bred in ranching programs, with large numbers sold internationally to collectors. Trade in these species is monitored under Appendix 2 of the Convention on the International Trade in Endangered Species (CITES) (United Nations Environment Programme, World Conservation Monitoring Centre, 2007).

Ornithoptera is an ideal genus to review for gynandromorphs as all species exhibit spectacular sexual dimorphism, such that extremely small areas of male tissue may be visible on a female wing, and vice versa. Moreover, the trade in aberrant *Ornithoptera* results in a high rate of reporting (if only in sales catalogues) and there is extensive literature describing and illustrating even the slightest variations observed in most species (e.g. D'Abrera 2003; Otani and Kimura 2001, Schäffer 2001). A thorough review of literature yielded a large number of *Ornithoptera* gynandromorph records, which are presented in Table 1. Only specimens clearly identified as natural gynandromorphs are presented because some fraudulent material has been 'manufactured' and advertised for sale on the internet in recent years (eg. a purported *O. x allotiei* (Rothschild, 1914) gynandromorph, consisting of the body and left wings of a female *O. victoriae regis* (Rothschild, 1895) with the right wings of a male *O. priamus urvillianus* (Guérin-Ménéville, 1830)). Elements of the *Ornithoptera* wing pattern defined by Haugum and

Low (1978) are used to describe the gynandrous phenotype of individual specimens. *Ornithoptera* taxonomy used here follows that presented by Parsons (2000) and Braby (2004).



Fig. 1 Mosaic gynandromorph of *O. priamus pronomus* collected by H. Elgner at 'Cape York', Queensland, on 17 February 1907. Specimen in the Australian Museum. above: upperside, below: underside.

Table 1. List of known *Ornithoptera* gynandromorphs, including for each specimen, collection locality, gynandromorph type, description of phenotype, literature references and current repository. Abbreviations: LH (left half); RH (right half); FW (forewing); HW (hindwing); D (dorsal wing surface); V (ventral wing surface); AM (Australian Museum); British Musuem (Natural History) (BM(NH)); IFTA (Insect Farming and Trading Agency, Papua New Guinea); P (various private collections).

Species Group Taxon	Locality	Type	Phenotype	Reference and Repository
<i>euphorion</i>	Australia (Kuranda, Queensland)	Mosaic	♂ overall with ♀ scaling on RH FW and HW. Halved genitalia.	Schäffer (2001) p
<i>richmondia</i>	Australia (Queensland?)	Mosaic	♀ overall with partial ♂ radial band on RHFW apex.	Sands and Scott 2002 Photograph only
<i>priamus</i> <i>pronomus</i>	Australia (‘Cape York’, Queensland)	Mosaic	Figure 1.	Common and Waterhouse 1972 (as <i>O. priamus</i> <i>poseidon</i>) AM:
<i>priamus</i> <i>admiralitus</i> Rothschild, 1915	Papua New Guinea (Trobriand Isl.)	Bilateral	LH male, RH ♀; abdomen bilaterally divided.	Haugum and Low 1978 p
<i>priamus</i> <i>admiralitus</i>	Papua New Guinea (Admiralty Is.)	Bilateral	Not figured; LH ♂; Received by IFTA.	Parsons 2000 Not specified
<i>priamus</i> <i>poseidon</i>	New Guinea (no locality)	Bilateral	LH ♂, RH ♀; abdomen bilaterally divided.	D’Abrera 2003 BM(NH)
<i>priamus</i> <i>poseidon</i>	Papua New Guinea (Aseki, Morobe Province)	Mosaic	LH ♂ w. ♀ scaling on HWV; RH ♀ w. ♂ scaling on HW. Abdomen w. ♂ genitalia, mostly ♀ dorsally, mostly ♂ ventrally.	Otani and Kimura 1998; Matsuka 2001 p

Table 1 continued

Species Group Taxon	Locality	Type	Phenotype	Reference and Repository
<i>priamus poseidon</i>	Papua New Guinea (Aseki, Morobe Province)	Mosaic	Predominantly ♂; RHFw mostly ♀ w. partial ♂ radial band; LH ♂ w. ♀ scaling on HW tornus and FW apex.	Matsuka 2001 p
<i>priamus poseidon</i>	Indonesia (Nabire, Papua province)	Mosaic	Predominantly ♀; FW w. partial ♂ radial streak and evidence of black median stripe. Overall markings diffuse w. much iridescence.	Otani and Kimura, 1998 p
<i>priamus urvillianus</i>	Papua New Guinea (Bougainville province)	Mosaic	LH ♀; RH ♂ w. limited ♀ scaling on HW. ♀ abdomen w. ♂ scaling. Ranchd.	Parsons (1999) IFTA
<i>croesus lydius</i>	Indonesia (Halmahera Is.)	Bilateral	LH ♂, RH ♀; abdomen bilaterally divided.	Parrott and Schmid, 1984 (in Parsons 2000) p
<i>victoriae regis</i>	Papua New Guinea (Bougainville province)	Mosaic	FW generally ♂ with ♀ markings; HW ♂ with ♀ pattern and ♂ scaling.	D'Abrera 2003 Howarth 1977 BM(NH)

Several *Ornithoptera* gynandromorphs that lack a formal literature reference but are otherwise well known to collectors via the internet are also presented. They are listed separately to those discussed in literature (Table 2). Specimens of female *O. priamus poseidon* and *O. aesacus* with iridescence on the wings not taking the form of defined markings are not considered to be gynandromorphs.

Australian *Ornithoptera* gynandromorphs

Of the three known Australian *Ornithoptera* gynandromorph specimens, only one resides in an Australian collection. This specimen, a mosaic gynandromorph of *O. priamus pronomus* (Figure 1), was collected at 'Cape York', Queensland, by H. Elgner on 17 February 1907. It is currently lodged

in the Australian Museum. This specimen was incorrectly referred to as a specimen of *O. priamus poseidon* (Doubleday, 1847) by Common and Waterhouse (1971). A gynandromorphic specimen of *O. euphorion* held in a private collection in Germany was figured on both surfaces by Schäffer (2001) and is described as originating from Kuranda, Queensland. It is most likely a captive bred specimen. A second, bred mosaic gynandromorph of *O. euphorion* is also known and will be discussed in a forthcoming article

A gynandromorph of *O. richmondia* figured by Sands and Scott (2002; pages 8 & 46) was predominantly female with a partial male radial band. It does not appear to have been collected and was not recognised in text as a gynandromorph by Sands and Scott (2002). The provenance of this photograph was not cited.

Table 2. *Ornithoptera* gynandromorphs sighted via the internet with no literature reference ('anecdotal' records).

Taxon	Locality	Type	Phenotype
<i>goliath</i>	Indonesia (Papua province)	Mosaic	Predominantly ♀; RHFW mostly ♂ w. slight ♀ influence; LHFw w. partial ♂ radial band. Ranched.
<i>goliath</i>	Indonesia (Papua province)	Mosaic	♀ w. partial ♂ cubital band on LHFw. Ranched.
<i>goliath</i>	?	Bilateral	LH ♂, RH ♀.

Other notable *Ornithoptera* gynandromorphs

Ornithoptera gynandromorphs have also been reported for *O. priamus*, *O. croesus lydius* (Felder, 1865) and *O. goliath* Oberthür, 1888, with the majority of specimens known from *O. priamus* subspecies (Appendix 1). The higher frequency of gynandromorphs for the latter taxa probably reflects its abundance through much of its natural range (Parsons 2000) and the quantity of specimens collected for trade, as opposed to a genuinely higher frequency of gynandromorphism. Trade in *O. priamus* subspecies represent some 47% of all *Ornithoptera* trade monitored by CITES, with at least 158,369 specimens exported from Indonesia, Papua New Guinea and the Solomon Islands between 1985 - 2005 (United Nations Environment Programme, 2007).

Three gynandromorphs of *O. goliath* were also examined from a series of detailed photographs published on the internet between 2001 - 2010 (Appendix 2). Additional *Ornithoptera* gynandromorphs known to the author from anecdotal reports alone have been omitted because it was impossible to independently verify their existence or the nature of their phenotype. It is hoped this paper will encourage those with gynandromorph specimens of any insect taxon to publish detailed photographs and descriptions in appropriate literature.

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MULTIPLE STYLOPISATION OF A PAPER WASP, *ROPALIDIA ROMANDI* (LE GUILLOU) (HYMENOPTERA: VESPIDAE)

¹CLYDE H. WILD and ²CASEY R. HALL

Griffith School of Environment, Griffith University Gold Coast Campus
Parklands Qld 4222 (E-mail: ¹Clyde.Wild@Griffith.edu.au ²Casey.Hall@student.griffith.edu.au)

Notes

Figure 1 shows a vespid wasp, *Ropalidia romandi* (Le Guillou, 1841) bearing three extruded, parasitic stylopids (Strepsiptera: Stylopidae). It is not absolutely clear from the photograph if these are all adult females or include male pupae, although given the host's behaviour it seems most likely that at least one female is present. The photograph was taken on 8 February 2010 in Southport, Queensland. The wasp was behaving strangely, crawling to the top of a blade of grass, falling off and the climbing another one. It is possible the female parasites manipulate the host's behaviour so that it climbs to a good position to encounter males.

Strepsipterans are rarely seen and enigmatic. In nearly all the female is a permanent endoparasite of the host, which, depending on the species, may belong to one of several orders. Unlike most insect parasitoids, strepsipterans do not kill their host at pupation and some species actually prolong their host's life relative to the unparasitised condition (Kathirithamby 1991).



Fig. 1. *Ropalidia romandi* bearing three stylopid strepsipterans extruded through intersegmental membranes (Photo: Casey R. Hall).

The male is a small, winged insect with greatly reduced forewings and flying hind wings, while in nearly all species the female is a reduced simplified permanent endoparasite in the abdomen of the host, occupying up to 80% of the abdomen's volume. Stylopisation renders the host sterile in most cases and changes in the host morphology, cuticle and behaviour are seen (Kathirithamby 1991). The male lives only a few hours after emergence from his host, eats nothing and mating takes place on the female's host (Pohl and Beutel 2008). Eggs hatch within the mother and the female then produces thousands or even millions of tiny active triungulin larvae (Pohl and Beutel 2008). These seek out suitable hosts and dissolve their way through its cuticle, commencing their parasitic lifestyle in a sac produced from host tissues which apparently protects the parasite from cellular defences by the host (Kathirithamby *et al.* 2003).

These very highly specialised parasites are so unlike other insects that their placement within the Insecta is still unresolved (Pohl and Beutel 2008). They have been hypothesised to be a family within the beetles, a separate order closely related to the beetles, an order close to the Diptera, and, given that the larvae of males have external wingbuds, not even included in the Endopterygota (Whiting 1998). Molecular biology work seems to be making some progress on "the Strepsiptera problem", as it is referred to in the literature, and a view is developing that these strange insects lie near the Diptera (Whiting *et al.* 1997, Wheeler *et al.* 2001), which is not inconsistent with their life-history, and some of their morphology and anatomy.

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THE LIFE HISTORY OF *ATTACUS WARDI* ROTHSCHILD (LEPIDOPTERA : SATURNIIDAE) FROM THE NORTHERN TERRITORY, AUSTRALIA

¹D.A. LANE, ²G. MARTIN & ³R.P. WEIR

¹3 Janda Street, Atherton, Qld 4883, d.l.lane@bigpond.net.au

²6 Rosebury Drive, Palmerston, NT 0830, g.martin@terrorbyte.com.au

³1 Longwood Avenue, Leanyer, NT 0812, Richard.Weir@nt.gov.au

Abstract

The life history of *Attacus wardi* Rothschild is described from the Northern Territory, Australia, and discussion is presented on the species biology, distribution and potential distribution, based on available specimen records and the known foodplant distribution. The only known larval foodplant is *Croton habrophyllus* Airy Shaw (Euphorbiaceae). Comparisons are made between this species and *Attacus dohertyi* Rothschild, *Attacus intermedius* Jurriaanse & Lindemans, *Attacus inopinatus* Jurriaanse & Lindemans, *Attacus erebus* Fruhstorfer and *Attacus aurantiacus* Fruhstorfer, from Indonesia and East Timor. Some initial assessment is presented on the conservation status of *Attacus wardi*.

Introduction

The genus *Attacus* Linnaeus, 1767 belongs to the Tribe Attacini, Subfamily Saturniinae and includes most of the species popularly referred to as Atlas Moths, due to their large size, distinctive wing markings and broad wing area and shape. The genus is widely distributed throughout the Asian and Indian region, from the Himalayas, south through India to Sri Lanka, southern China, the south east Asian mainland, the Philippines, extending through Indonesia to northern Australia. Peigler (1989) in a revision of the genus *Attacus* lists fourteen species.

Attacus wardi Rothschild 1910 (Fig 15) is an Australian endemic and the only known *Attacus* species from northern Australia. It was first collected and recorded from the Northern Territory, Australia in February–May, 1909, when F.P. Dodd collected a number of cocoons of this species from “Port Darwin” (Peigler 1989). Dodd subsequently bred quite a number of specimens (about 50) from wild collected cocoons taken from “Port Darwin” and distributed most of these adult specimens to many of the world’s museums and some private collections (Peigler 1989). Unfortunately no information was published or provided by Dodd on any life history or biological details of the species, although some notes on adult emergence times were reported by Dodd (in Oberthur 1916).

Since the first collection of the species in 1909-1910, the species remained completely unknown, with no further observations being made until a solitary adult male was collected at light by E.D. Edwards at Black Point, Cobourgh Peninsula, Northern Territory in January, 1977 (E.D. Edwards pers. comm., Peigler 1989). Since 1977, no additional records or further observations were made, until some limited evidence was observed by or presented to the authors of the species’ occurrence on Bathurst and Melville Islands,

(collectively known as the Tiwi Islands), N.T. during 2005, 2007 and 2008. The presence of the species was again confirmed on Melville Island during March, 2009, and March 2010, where adult moths, wild eggs, first, second, and third instar larvae, and pupal exuviae (empty cocoons) were found by the authors, and detailed observations were made of adult moth behaviour and of its early stages. During March 2010 the species was also found at Gunn Point near Darwin, where wild eggs were collected.

Attacus wardi was first described and subsequently recorded by other authors as a subspecies of *Attacus dohertyi* Rothschild 1895, viz *Attacus dohertyi wardi*, until a revision of the genus *Attacus* raised *wardi* to full species status (Peigler 1989). The distinctive life history of *Attacus wardi* described below confirms its full species status.

Life history

The known larval foodplant (Fig 14) *Croton habrophyllus* Airy Shaw (Euphorbiaceae) is a tree that is endemic to Western Australia and the Northern Territory (Hyland & Whiffin 1993), and grows to a height of 8-10 metres within monsoon forest areas and fringing forest areas along watercourses, from sea level to approximately 100 metres elevation. Trees of between 3-7 metres in height and growing either along the outer margins of, or along transect tracks through the monsoon forests appeared to be particularly favoured by ovipositing females of *A. wardi*. It is believed that such situations provided adequate flight space for the large female moths - however these observations may more reflect the authors' observational techniques, as many of the crowns of tall *Croton* trees growing within the monsoon forest areas were more difficult to adequately access. In fact it is likely that the upper crowns of tall *Croton* trees are the favoured oviposition sites of the moths, as typical larval feeding patterns within the upper canopy were regularly observed from the ground. All wild eggs found had been laid in the upper crown of foodplant trees on the underside of mature leaves.

Egg (Fig 1). Oval, flattened type, approx 2.6x2.1x1.6mm high, pale brownish white, laid singly or in a line of two, three or four adjacent but separated by several millimetres on the underside of the foodplant leaf, lying near to the leaf margin and usually no further than 1cm from the leaf margin. Eggs have a coating of a pale brown secretion which appears to be an adhesive agent for affixing the eggs to the leaf surface. Wild *A. wardi* eggs were observed to have an incubation period of at least 10 - 15 days.

First instar larva (Figs 2-3). Length 5-10mm. Head, prolegs, thoracic and abdominal segments all jet black. Each segment carries six long fleshy, erect scoli, two dorsal, one subdorsal each side, one scoli below spiracles, all jet black. All scoli carry a series of radial black spines at apex. Larval duration 4-5 days.

Second instar larva (Figs 3-4). Length 10-16mm. Head and thoracic legs light brown. Prolegs, thoracic and abdominal segments white, but with mixed pale brown intermittent spotting. Erect scoli much longer than those of first instar, equally fleshy, all coloured white with apex of scoli adorned with a ring of white "cotton wool" like fleshy appendages and short white radial setae. Scoli on anal segments shorter than those on abdominal segments. Anal prolegs white. Abdominal segments 1&2, 7&8 each with a lateral red area that lies between the subdorsal scoli and the scoli below the spiracles. Thoracic and abdominal segments are lightly coated in a fine whitish powder. Larval duration 7-8 days.

Third instar larva (Fig 5). Length 16-37mm. Head and thoracic legs light brown. Prolegs, thoracic and abdominal segments all white, but adorned with intermittent dark green spotting. Long fleshy scoli coloured white, adorned at apex as in second instar larva with "cotton wool" like fleshy appendages and short white setae – those on abdominal segments sloping backwards. Thoracic and abdominal segments covered with a white wax-like powder which can be easily dislodged if the larva is touched or handled in any way. Anal prolegs same colour as prolegs and body, but shows the first discernable sign of a "false eyespot" lateral marking. Prolegs each with a series of short white basal setae. Larval duration 9-10 days.

Fourth instar larva (Figs 6-8). Length 37-60mm. Head and thoracic legs pale greenish white. Prolegs, thoracic and abdominal segments all white but adorned with intermittent dark green spotting; spotting is larger and more distinctive on abdominal segment 8 and anal prolegs. Scoli long and fleshy, much thinner than those of third instar, coloured white but with upper half pale blue – (this blue colouring is less pronounced in early fourth instar larvae), becoming darker after two days. Scoli with short white setae arising from various lengths along the scoli stem. Scoli on abdominal segments sloping backwards as in third instar. Spiracles very pale blue, ringed white. Larval body carries patches of white wax-like powder, but in lesser quantity than that of third instar. Anal prolegs adorned with a black lateral "false eyespot", lightly pitted. Scoli on anal segments greatly reduced, three dorsal rows of low domed shape, and coloured light blue; an anterior row of 4, with two lower parallel posterior rows comprising 2 scoli each. These scoli represent the morphological change to defensive glands, as also recorded for *A. dohertyi* (Paukstadt & Paukstadt 1993), however their function as such could not be determined. Larval duration 12-13 days.

Fifth instar larva (Figs 9-10). Length 60-85mm. Head, thoracic legs, prolegs, and body segments all light green, closely matching the colouration of the foodplant leaves. Dark green intermittent spotting faintly indicated on thoracic segments, but more pronounced on abdominal segment 8 and anal prolegs. Long thin scoli light green at base, white mid section, with dark blue upper one third; those on abdominal segments sloping backwards as in fourth



Figs 1-7. *Attacus wardi*: (1) egg; (2) first instar larva; (3) first & second instar larva; (4) second instar larva; (5) third instar larva; (6) early fourth instar larva; (7) fourth instar larva, lateral view.

instar; each white and dark blue scoli section is also adorned with short white and blue setae respectively. Some small amounts of white waxlike powder present in the "folds" at segmental junctions. Spiracles coloured as on body, ringed lighter green. Anal prolegs with black "false eyespot" lightly pitted. Eight much reduced, low dome shaped scoli on anal segments coloured darker green, representing defensive glands but their functionality was not confirmed. The larval body is large and bulky. Larval duration 11-12 days.

Sixth instar larva (Figs 11-13). Length 85-115mm. Very similar to fifth instar, but more bulky. Scoli of similar colour to fifth instar, but shorter in length. No visible defensive gland scoli on anal segments. Intermittent dark green spotting not distinct, and only present on abdominal segment 8 and anal prolegs. Larval duration 8-9 days.

Pupa and cocoon (Figs 16-17, 18-19). Pupa dark brown, approaching black, stout and ovoid in shape, length 32-38mm, width 18-22mm at wingcases. Male antennal covers much broader than female. Hindwing wing cases extend past that of the forewing. Cremaster blunt, rounded. The only available (to the authors) pupae for comparison are those of *Attacus erebus* Fruhstorfer from Sulawesi, Indonesia (DAL coll., legacy S. Naumann, Germany) – the pupa of *erebus* is slightly larger than but similar in shape to that of *wardi*, and light brown in colour. The pupa of *A. dohertyi* is brown, whilst that of *A. inopinatus* is red brown (Paukstadt & Paukstadt 1993,1992).

The location of wild observed cocoons of *A. wardi* indicate that in some situations mature larvae leave the foodplant tree canopy to reach lower sections of the tree, or leave the tree to reach intertwining vines or understorey shrubs, on which to pupate. Cocoons are cylindrical or broadly cylindrical, elongated, tapering at each end, 60-90mm in length, 25-40mm wide at the midsection, are of double walled construction, and have either a single or several leaves wrapped around the outer cocoon, all tightly attached with silk, which serves to camouflage the cocoon to a remarkable extent; the impression is one of a dead hanging leaf. The leaf stalk and adjacent stem is also wrapped in silk, effectively securing the cocoon from falling away. Colour of cocoons ranges from light tan to coffee brown, and is slightly darker than that of *A. erebus*. During the final process of pupation, *A. wardi* larvae, once suitably enclosed by their newly spun white silken cocoon, and also housed by the wrap-around leaf, appear to regurgitate a brown liquid which initially saturates the cocoon walls, with some excess brown liquid dripping and falling away from the cocoon. This process gives the cocoon its distinct tan or coffee brown colour. Its purpose is not clearly understood, but it is believed that it acts as a drying and sealing agent to protect the inner pupa from fungal, bacterial or viral infections, and possibly dessication. Adult moths have been observed to emerge from their cocoons after intervals of 21 -30 days, or the cocoons may enter diapause for periods of up to twelve months.

Dodd, in his 1916 recorded observations of his trip to Port Darwin in 1909-1910, when referring to the cocoons that were collected, stated "Most of these emerged within three months time, some up to six months after our return to Kuranda, but the last one duly emerged after remaining in pupa for over 14 months."

Biological observations

Of numerous eggs found in the wild, quite a few were found to be parasitised by a minute species of wasp (*Agiommatus* sp., Superfamily Chacidoidea, Family Pteromalidae, Subfamily Pteromalinae. (identification John La Salle, E.D. Edwards, pers. comm., specimens deposited in ANIC)). Species of wasp from this genus have been recorded parasitising moth eggs in *Antheraea* (Saturniidae), *Acherontia* (Sphingidae) and those of skippers belonging to *Erionota* (Hesperiidae). The genus is distributed in Africa (including Madagascar), South Asia to Australia (E.D. Edwards, pers. comm.). This minute species of *Agiommatus* appears to be a primary population control agent of *A. wardi*, and by our observations approximately 35% of wild eggs had been parasitised. Each parasitised egg had only a single adult wasp emerge, executed by cutting a minute exit hole through the egg wall.

First instar larvae appear to be fairly tenuous of life – they first devour the greater part of the hatched eggshell, leaving only a basal plate or part of the wall. A period of inactivity of 4 – 12 hours then follows, with those larvae remaining motionless on the leaf underside, usually near to the remnant eggshell. Two such first instar larvae did not begin to feed, and perished – however after this inactive period all others began to feed by cutting irregular patches from the leaf margin of semi juvenile leaves. By second instar, larvae wander and become widely dispersed through the upper tree.

Larval development through the six instars is over 51-56 days, and all instars displayed periods of continuous feeding followed by equal periods of inactivity of up to several hours. Apart from short periods of moving around the foodplant tree to seek fresh feeding areas, larvae of all instars mostly remained on the underside of the foodplant leaves, or in the case of fifth and sixth instar individuals, sometimes upside down on small twigs. Second to sixth instar larvae displayed a high degree of protective camouflage amongst their foodplant leaves. First instar larvae generally resembled brown or blackish leaf blemishes that were a feature of mature foodplant leaves, and were equally well camouflaged.

On Melville Island adult moths are often taken by Boobook Owls (*Ninox novaeseelandiae*) after they have been attracted to street lights. Here the birds appear to patrol around certain street lights, awaiting the arrival of any large bodied moths. Our observations of the regular assemblage of remnant moth wings including *Attacus* on the ground below certain street lights was testament to the birds' activity. Green Tree Ants (*Oecophylla smaragdina* (Fabricius, 1775)) are known to prey upon saturniid larvae in general

(DAL pers obs). Foodplant trees with any Green Tree Ant activity never contained eggs or larvae of *A. wardi*.

While our field observations were conducted over a brief time interval during March 2009 and March-April 2010, and to date the only confirmed foodplant is *C. habrophyllus*, there is a strong probability that other foodplant trees would be utilised, particularly other plants belonging to Euphorbiaceae. *Croton tomentellus* F. Muell. grows in similar situations to *C. habrophyllus*, though it is a slightly smaller tree in height, and also has a slightly wider distribution, extending from Western Australia to the Northern Territory, through to north east Queensland (Hyland & Whiffin 1993). *Omolanthus novo-guineensis* (Warb.) Lauterb. & Schumann (Euphorbiaceae) also has a similar distribution and habitat to both above *Croton* species, ranging from Western Australia through to north east Queensland (Hyland & Whiffin). A number of larvae of all instars of *A. wardi* were offered *O. novo-guineensis* as food, and readily accepted this and developed at a comparable rate to those on *C. habrophyllus*.

Discussion

Some Australian, Indonesian and Papuan species of Saturniidae are quite sedentary; adults are not often observed, in cases due to extremely localised distributions, extremely short flight periods that may be directly tied with seasonal rainfall or relative humidity, and relatively short adult lifespans (estimated 3-5 days, DAL pers. obs.). Nocturnal flight periods may be either late evening or early morning. *Attacus wardi* appears to fit very well into this category, and its flight periods, biology and sedentary behaviour can be directly compared with *Attacus dohertyi* from Timor (DAL, pers. obs.). Available records of adult *A. wardi* emergences (including from Dodd's original material, Peigler 1989) list the months of January to February, extending to early March. Our observations of wild adult moths confirm a nocturnal period of flight activity between 23.00 – 03.00 hours, and combined with observations of some Tiwi Islands residents, also confirm early to late March as the flight season, provided good monsoonal rainfall occurs. Our observations of eggs, first, second and third instar larvae, and empty cocoons in late March, gives further credence to March being part of the flight season of *A. wardi*.

Of historical interest, during 1935 Walter Dodd published a series of newspaper articles titled "Meanderings of a Naturalist" in the "North Queensland Register" published out of Townsville (G. Monteith, pers comm). In one such article dated 9 March 1935, Walter describes the trip to Darwin with his father in 1908, and when referring to *A. wardi* states "We had many pupae, and whilst the moths were emerging, males of the species were occasionally attracted from the jungle several miles away".

Observations of the flight activity of *A. dohertyi* in East Timor (DAL & M. Lane, 2002 & 2004) confirmed that adult emergence is triggered by the first

substantial wet season rainfall. After good rainfall in October 2002 that followed several months of little to no rainfall, a significant number of adult moths were collected at lights at Bobonaro for a period of about one week (always between 2300 – 0300 hrs), but then populations quickly tapered and no further adult activity was observed.

Comparisons

Peigler (1989) lists the characteristics that clearly separate adults of *A. wardi* from those of three geographically adjacent and closely related species, viz *A. dohertyi* (Timor, Romang and Damar Is. (Lesser Sunda Islands)), *A. intermedius* (Tanimbar Islands), and *A. inopinatus* (Flores (Lesser Sunda Islands)). Paukstadt & Paukstadt (1992 & 1993) described and illustrated the life histories of *A. inopinatus* and *A. dohertyi* with black and white photographs. Peigler & Wang (1996) documented in colour photographs the life history of *A. dohertyi*. Peigler (1989) stated that *A. intermedius* was so named because its authors intended to convey the point that this moth appears intermediate between *A. dohertyi* and *A. wardi*, believing that all three species were conspecific. The life history of *A. intermedius* remains unknown.

All larval instars of *A. wardi* are readily distinguished from those of both *A. dohertyi* and *A. inopinatus*. Firstly the jet black colouration of the first instar larva of *A. wardi* is unique amongst all known species of *Attacus*, and is quite unlike the first instar larva of either *dohertyi* or *inopinatus*, which are both coloured white with some degree of black striping. Compared with those of *dohertyi*, the second, third, fourth and fifth instar larvae of *wardi* show noticeable differences in colour, shape and form of scoli, prolegs, thoracic and abdominal segments. The sixth instar larva of *wardi* is closer to that of *dohertyi*, but differs from that species in the extent of upper blue scoli colouration. Second to sixth larval instars of *inopinatus* differ considerably from those of both *wardi* and *dohertyi*, particularly in shape, length and colouration of scoli, and also in colouration of prolegs, thoracic and abdominal segments. The final instar larva of *Attacus aurantiacus* Fruhstorfer (Nassig & Taschner, 1996) from the Kai Islands, Indonesia differs significantly from all of the above species, with dorsal and lateral scoli coloured bright red and dark blue. Based on sixth instar larval characters, *A. wardi* appears to have a closer affinity to *A. dohertyi* than to all other species, and possibly displays close ancestral ties with *dohertyi*.

Distribution and conservation status

To date, *Attacus wardi* has remained a poorly known and understood species in terms of its known distribution, flight times, range of foodplant preferences, and its specific habitat requirements. Our observations, combined with historic records, indicate that the species is restricted to the monsoon forest areas of the northern coastal areas of the Northern Territory, including but not limited to Darwin, Gunn Point, the Tiwi Islands, and



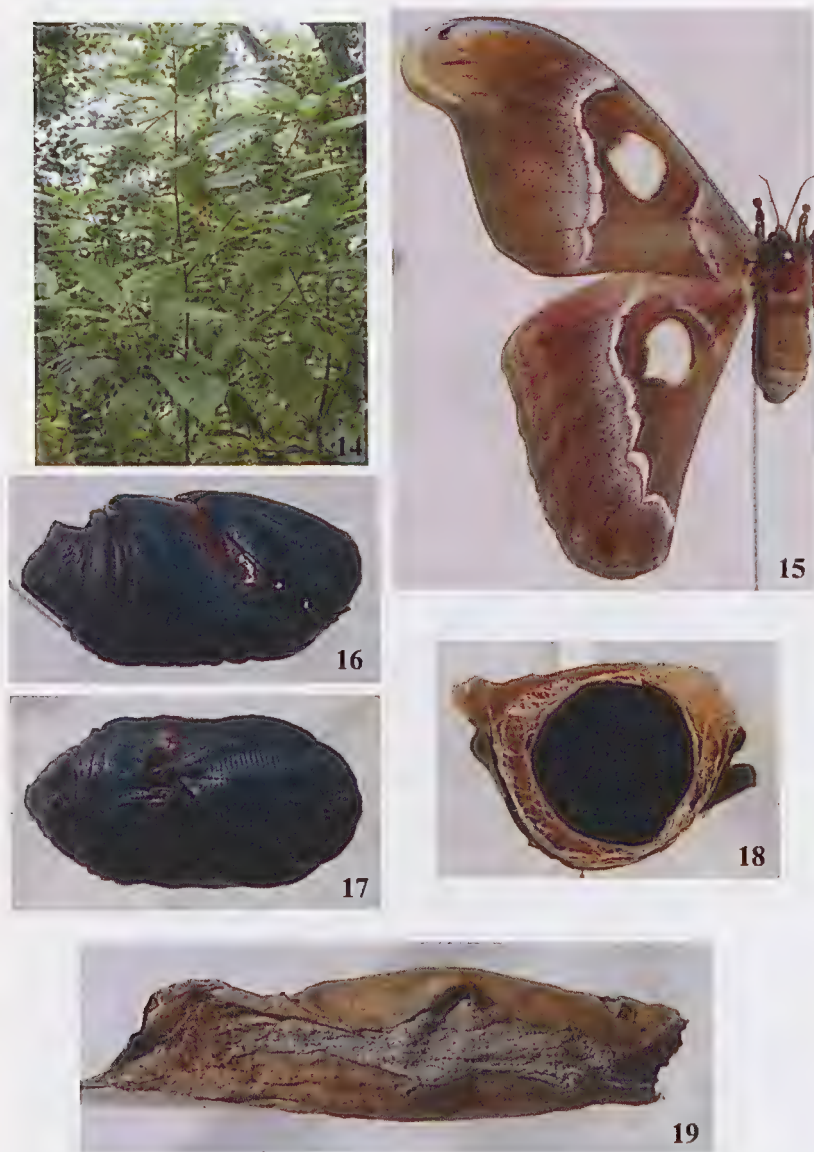
Figs 8-13. *Attacus wardi*: (8) fourth instar larva, dorsal view; (9) fifth instar larva, lateral view; (10) fifth instar larva, dorsal view; (11) sixth instar larva; (12) sixth instar larva, frontal view; (13) sixth instar larva, rear segments & anal claspers.

Cobourgh Peninsula (Garig Gunak Barlu National Park), and adults principally fly during the wet season months (January to March). Local adult population numbers can be quite high but for extremely limited duration, and like its counterpart *A. dohertyi*, adult nocturnal flight activity is limited from the late evening to early morning. However, should good summer storms provide suitable conditions, it is also quite feasible that an earlier generation of *A. wardi* might occur around October to December. Based on the published distributional data of *Croton habrophyllus* as a known foodplant source, and combined with the seasonal rainfall distribution of the Northern Territory, *A. wardi* may occur as far east as Nhulunbuy and Groote Eylandt, as well as the many intervening coastal monsoon forest areas, where extensive areas of suitable habitat remain. It is our belief that several other foodplant tree species from several plant families will be found to be used by *A. wardi*, as is the case with other species of *Attacus* (Peigler 1989), and also other closely related genera, such as *Coscinocera* Butler (DAL pers. obs., Common 1990).

Peigler (1989), under material examined, lists two male specimens of *A. wardi* held in the American Museum of Natural History (AMNH), New York, that carry data labels citing "Cape York" and "North Cape York Peninsula" in Queensland as localities. These localities are considered most unlikely by the authors, as the zoogeographic region of Cape York Peninsula is considered far more closely aligned with the Papuan/Australian faunal area than that of Indonesia. However, a close lookout should still be maintained by entomologists particularly those visiting the north western coastline of Cape York. Peigler (1989) also considered *Coscinocera hercules* Miskin to be sympatric with *A. wardi* at Darwin – this is incorrect as within Australia *C. hercules* is restricted to north eastern Queensland.

The forest verges of the 'Top End' are a constantly changing interface, where pioneer trees including *Croton* species are a component of an ever expanding or contracting monsoon forest, dependant on rainfall intensity and seasonality, combined with the frequency and intensity of fire regimes. It is our opinion that any component of irregular or frequent fires that penetrate the monsoon forest verges would be severely destructive to populations of *A. wardi*. The observed tendency for mature larvae to form their cocoons on mid to lower parts of the foodplant trees, or on understorey shrubs, would leave them extremely vulnerable to any fire activity, especially as the species undergoes dry season diapause as a pupa.

The observed habit of some mature *A. wardi* larvae leaving the upper forest canopy to pupate at lower levels may be an adaptation to having developed some degree of protection against high cyclonic winds. It is of particular interest to compare this behaviour with that of several north Queensland species of moth, whose specific habitat is periodically exposed to cyclonic disturbance. The observed larval habits of leaving their feeding zones in the forest canopy and forming cocoons on lower sections of their foodplant trees,



Figs 14-19: *Attacus wardi*: (14) foodplant tree, *Croton habrophyllus*; (15) adult female, ex pupa; (16) male pupa, lateral view; (17) male pupa, ventral view; (18) cocoon, cross sectional view, depicting double walled construction; (19) cocoon.

or on understory trees or shrubs, may well be an adaptation to avoiding the high canopy winds of infrequent cyclones. In particular, three large moth species that exhibit this behaviour are *C. hercules*, the uraniid moth *Alcides metaurus* (Hopffer), and the anhelid moth *Chelepteryx chelepteryx* (R. Felder). The latter species feeds as a larva within the forest canopy of the tall wet sclerophyll and rainforest areas at high altitude on the southern and western Atherton Tablelands. In this situation mature larvae lower themselves onto understorey shrubs and trees to spin their cocoons (DAL pers. obs.), whereby the large heavy pupae appear to gain some protection from high winds.

In the Northern Territory some introduced plant and insect pest species may prove to be of concern to populations of *A. wardi* – Gamba grass (*Andropogon gayanus* Kunth.) is spreading across the ‘Top End’, and burns fiercely and hot, potentially providing a threat to the monsoon forest verges and their extent. The introduced Yellow Crazy Ant (*Anoplolepis gracilipes* (Fr. Smith)) occurs in the East Arnhem region near Gove, and colonies of this ant are notorious for destructively devouring all available food resources in the near vicinity.

The habitat requirements of *A. wardi* as observed at Gunn Point and Melville Island are reasonable sized pockets of Monsoon Forest, of a possible minimum size of around 8 hectares but preferably up to 20 hectares or larger, containing good numbers of *Croton* foodplant trees. The pockets should stand in reasonably close proximity to each other, so that adult moths can intersperse readily between them. The greater the number of such Monsoon Forest pockets, combined with their near proximity to each other, the more the secure are *A. wardi* populations inhabiting them.

Historic maps of Darwin and environs suggest that at one time extensive bands of Monsoon Forest extended almost continuously from the Darwin Esplanade, through East Point, to Nightcliff, Casuarina and Lee Point. It is our opinion that this band of Monsoon forest was the locality from which Dodd’s 1909 historic specimens were collected. Sadly the greater part of this habitat is now gone, with the remaining remnant Monsoon Forest now found only at East Point and Lee Point. Interestingly, at both of these sites a number of large and small *Croton* trees are well established, but our searches have so far failed to find early stages of *A. wardi*. These areas in theory are indeed suitable habitats, but we feel that they are currently too isolated from each other, without intervening pockets, and hence are too small to support a viable population of *A. wardi*. However, should a suitable replanting programme ever be instigated, to interconnect these remnant pockets with suitable intervening Monsoon Forest pockets containing adequate *Croton* and other Euphorbiaceae trees, then the opportunity may then arise to re-introduce *A. wardi* to the Darwin coastal area.

At present, the conservation status of *A. wardi* seems fairly secure, with good populations known from the Tiwi Islands and Gunn Point, coupled with adult records from Cobourg Peninsula (Garig Gunag Barlu National Park). Populations are almost certain to be found at intermediate localities between Gunn Point and Cobourg Peninsula where extensive habitat remains, and possibly through to the Nhulunbuy area. The protected species status of *A. wardi* does not appear justified, particularly as such little research has been undertaken on its biology and habitat requirements. A conservation status listing as Data Deficient would be more appropriate – with a recommendation that much more detailed research be undertaken into the species biology and distribution. Habitat protection is far more relevant to the long term tenure of *A. wardi*, particularly in consideration of the current extremely poor management of fire regimes across the ‘Top End’.

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